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A Laboratory Comparison of Clockwise and Counter-Clockwise Rapidly Rotating Shift Schedules, Part I. Sleep

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16. Abstract:

INTRODUCTION. Many air traffic control specialists work relatively unique counter-clockwise, rapidly rotating shift schedules. Researchers recommend, however, that if rotating schedules are to be used, they should rotate in a clockwise, rather than a counterclockwise direction. Unfortunately, few studies have examined clockwise and counter-clockwise, rapidly rotating shifts. This study was designed to partially remedy this lack by examining the effects of both types of schedules on sleep duration, timing, and quality. METHODS. Participants (n=28) worked a week of day shifts (0800-1600), followed by two weeks of either a Clockwise (n=14) or Counter-Clockwise (n=14) shiftwork schedule, including early morning (0600-1400), afternoon (1400-2200), and midnight shifts (2200-0600). Participants recorded sleep data in daily logbooks and wore wrist activity sensors to provide an objective source of sleep/wake data. RESULTS. Both groups reported less sleep before the early morning shifts ($\underline{M}_{Clockwise}$=5.1h; $\underline{M}_{counter\text{-}clockwise}$=5.5h) than before the afternoon shifts ($\underline{M}_{Clockwise}$=7.5h; $\underline{M}_{counter\text{-}Clockwise}$=7.9h). The Clockwise group reported an average of 7.2h of sleep during the night before the midnight shifts and a nap during the day of 0.9h. In addition to a nighttime sleep of 6.0h, the Counter-Clockwise group also took a nap before the midnight shifts of 2.2h. Objective sleep data and subjective sleep quality ratings are also reported. DISCUSSION. While these data indicate that a longer concentrated sleep period is obtained prior to the midnight shift on the Clockwise rotation schedule, they do not fully support the hypothesis that a clockwise rotation will result in less sleep disruption.

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A Laboratory Comparison of Clockwise and Counter-Clockwise Rapidly Rotating Shift Schedules, Part I. Sleep

INTRODUCTION

Debate exists in the shiftwork literature regarding the benefit of rotating versus fixed-shift schedules (Folkard, 1992; Wedderburn, 1992; Wilkinson, 1992). There is little debate, however, that if shift schedules are to rotate, they should do so in a clockwise direction to maximize the time off between shifts and take advantage of the delaying properties of the circadian clock (Barton & Folkard, 1993; Czeisler, Moore-Ede, & Coleman, 1982; Folkard, 1989; Knauth, 1993). The primary arguments against the counter-clockwise rotation of shifts, especially for rapidly rotating schedules in which shifts change every two or three days, are that it results in greater disruption of circadian rhythms and shortened sleep periods as a result of reduced time off (Czeisler, Moore-Ede, & Coleman, 1982; Folkard, 1989; Rosa et al., 1990). Others (Akerstedt, 1990; Barton & Folkard, 1993) concede, however, that despite the arguments against counter-clockwise rotations, there is very little empirical evidence to support this view. Instead, Turek (1986) asserts that circadian rhythms and the sleep-wake cycle will be similarly perturbed on either a clockwise or counter-clockwise shift rotation.

Given this discussion, it is interesting to note that Air Traffic Control Specialists (ATCSs) in the United States have successfully worked variations of the counter-clockwise, rapidly rotating shift schedules since the early 1970s. The most common and well-known of these schedules is the so-called 2-2-1 (Cruz & Della Rocco, 1995) that involves working two afternoon shifts, followed by two morning shifts and one midnight shift. Summarizing laboratory and field research on the 2-2-1 schedule, Della Rocco, Cruz, and Schroeder (1995) demonstrated a characteristic decline in sleep duration across the workweek. Specifically, sleep duration declined from around 8 hours before the two afternoon shifts to roughly 5-6 hours before the two morning shifts. This was followed by a nap of approximately 2.5-3.5 hours during the daytime quick-turn before the midnight shift. While the timing of sleep co-varied with the start of the shift in the laboratory, sleep times in the field appeared more stable. That is, the timing of sleep onset was consistent, and wake-up times shifted only to accommodate earlier shift start times. These data are in agreement with findings reported by Folkard (1989) regarding the difficulties associated with reduced sleep due to early start times for the morning shift.

While the 2-2-1 counter-clockwise rotating schedule has been utilized by ATCSs in the U.S. for years, surprisingly few studies have examined the effect that advancing and delaying schedules have on sleep-wake patterns and performance. One such study, a survey conducted by Barton and Folkard (1993) of shiftworkers in five different industries, revealed that those working advancing (counter-clockwise) schedules reported poorer physical and psychological health, greater sleep disruption, more social and domestic disruption, and lower job satisfaction than those working delaying (clockwise) shift schedules. In a study of microelectronic factory workers, changes in sleep-wake patterns were studied as individuals moved from a counter-clockwise shift system to a clockwise shift system (Lavie, Tzischinsky, Epstein, & Zomer, 1992). The authors concluded that results for sleep-wake cycle and subjective measures of fatigue supported the clockwise rotation of shifts. Most of the results, however, were not statistically significant. Likewise, other studies supporting clockwise rotations have been confounded by concomitant changes in other aspects of the schedule design (Czeisler, Moore-Ede, & Coleman, 1982; Knauth & Kiesswetter, 1987).

The question remains whether clockwise shift rotations result in better adaptation and performance as the literature would suggest, particularly in the safety-critical environment of air traffic control. Notably, many air traffic controllers (ATCs) in the U.S. Air Force (USAF) work a schedule that is, in many ways, the clockwise counterpart to the counter-clockwise 2-2-1 schedule worked by FAA ATCSs. The USAF schedule rotates every 2 days through morning, afternoon, and night shifts and then provides 48 hours off in a 6-day workweek. Luna, French, Mitcha, and Neville (1994) examined this schedule with 14 USAF ATCs and found that diurnally oriented circadian rhythms were maintained.

Indeed, while there are a few studies investigating the direction of shift rotation, there appear to be none that directly compared rapidly rotating advancing and delaying shifts. The purpose of the present study was to directly compare clockwise and counter-clockwise rapidly rotating schedules. Specifically, this study examined the effects these schedules had on sleep duration, sleep onset and awake times, sleep quality ratings, subjective ratings of sleepiness, and subjective ratings of mood/activation.

METHODOLOGY

To examine differences between rapidly rotating clockwise and counter-clockwise shift schedules, a 3-week protocol was designed using groups of 5 participants at a time. The direction of rotation was balanced such that the first group was assigned to the clockwise rotation; the second group was assigned to the counter-clockwise rotation, and so on. An array of sleep, subjective fatigue, performance, physiological, and biochemical data was collected. However, this paper will focus on only those variables related to sleep and subjective measures.

Participants

Participant Recruitment and Selection

Participants were initially recruited and screened by a private contractor. Upon arriving at the Civil Aerospace Medical Institute (CAMI) for the first time, participants were briefed on the study protocol and signed the informed consent. They were then administered a number of screening tests, including a drug and alcohol use questionnaire, the Shipley Institute of Living Scale verbal and abstract reasoning tests (Zachary, 1986), the Digit Span Forward and Backward tests, and an FAA Class II medical examination (14 CFR, Part 67, Federal Aviation Regulation). Participants were required to score a minimum WAIS-R equivalent of 102 on the Shipley test to ensure that subject intelligence was similar to students entering the FAA Academy ATCS Nonradar Screen (Della Rocco, Milburn, & Mertens, 1992). In addition, participants were required to recall 4 digits on both the forward and backward digit span and to pass an FAA Class II medical exam. All participants were paid.

Demographics and Group Assignment

Thirty people between the ages of 20 and 55 (M = 41.2 years) were recruited and screened from the general population to participate in the study. Two participants withdrew before completing the protocol. The remaining participants were assigned to either the clockwise (n = 14) or counter-clockwise (n = 14) rotation condition based on the order in which they were recruited. The clockwise rotation included 7 males and 7 females with an average age of 40.6 years (sd = 9.4 yrs.), while the counter-clockwise rotation included 5 males and 9 females with an average age of 41.9 years (sd = 9.0 yrs.). The majority of participants were caucasian (86%), married (57%), and had at least some college (89%). All were high school graduates, non-smokers, and light- or non-users of caffeine and alcohol. Participants represented a range of occupations from professional to trades with only one who was unemployed.

Procedures and Apparatus

Protocol

Participants in the study reported to the laboratory for 8 hours per day, 5 days per week, for 3 weeks. Participation during the first week (Monday-Friday) for both shift rotation conditions took place during the day shift (0800-1600). It began with an orientation to the laboratory and a detailed daily schedule for the study. Two one-time questionnaires were completed, a Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976) and a biographical questionnaire. In addition, participants were given physiological monitoring devices and daily logbooks, and they were trained on their use. Finally, participants were trained on the Multiple Task Performance Battery (MTPB) and the Bakan Vigilance Task. The physiological monitors and all sensors (except the chest band) were worn 22.5 hours per day to accommodate a 1.5-hour break for showers and leisure activities. The only restriction was that the monitor should not be removed while sleeping or napping. The chest band sensor was only worn while working in the laboratory. The Bakan Vigilance Task was administered at the beginning and end of each workday, and the MTPB was performed three times each day. The daily protocol is presented in Table 1.

During the next two weeks, participants worked either the clockwise or counter-clockwise shift rotation schedule shown in Table 2. Note that the clockwise rotation allowed 24 hours off between each shift rotation and a 48-hour weekend before returning to work again. The counter-clockwise rotation allowed only 8 hours off between each shift rotation and an 80-hour weekend before returning to work again.

Participants were instructed to treat their participation in the study as a full-time job and to refrain from drinking alcohol or taking any drugs or medications during the course of the study, with the exception of ibuprofen, birth control pills, estrogen replacement, and non-drowsy formula allergy medications such as Claritin™. In addition, subjects were instructed not to consume any caffeinated beverages or chocolate and were not allowed to eat bananas

Table 1

Daily Experimental Protocol

Time (in hours)		Activity
Start	End	
00:00	00:30	Download & initialize Miniloggers; subjective ratings; collect saliva
00:30	01:00	Bakan Session 1
01:00	02:30	MTPB Session 1
02:30	02:45	Subjective ratings; collect saliva
02:45	03:15	Break
03:15	04:45	MTPB Session 2
04:45	05:00	Subjective ratings; collect saliva
05:00	05:30	Meal Break
05:30	07:00	MTPB Session 3
07:00	07:30	Bakan Session 2
07:30	08:00	Download & initialize Miniloggers; subjective ratings; collect saliva

Table 2

Clockwise and Counter-Clockwise Shift Rotation Schedules

Clockwise Rotation			Counter-Clockwise Rotation		
Day	Work Hours	Hours Between	Day	Work Hours	Hours Between
Monday	0600-1400	16	Monday	1400-2200	16
Tuesday	0600-1400	24	Tuesday	1400-2200	8
Wednesday	1400-2200	16	Wednesday	0600-1400	16
Thursday	1400-2200	24	Thursday	0600-1400	8
Friday-Sat	2200-0600		Thur-Friday	2200-0600	

because of potential interference with the radioimmunoassays for cortisol. Diet was not otherwise controlled in the study. Participants were tested with the Intoxilyzer 9000™ breath alcohol test at the beginning of each workday to ensure compliance with the study protocol. None of the participants tested positive during the study.

A final day of testing on Day 22 of the study included a final Bakan test session, checking in equipment, and filling out an exit questionnaire regarding the study experience and a group cohesiveness questionnaire. Bringing participants back to the laboratory on this final day was done to mitigate an end-of-study effect at the end of the previous week and to allow for physiological data collection on the weekend following the last shiftwork week.

Logbooks

Information regarding sleep, sleep quality, mood, sleepiness, food and beverages, exercise, naps, removal of physiological monitors, symptoms, and comments was collected in daily logbooks, modified from those developed by the National Aeronautics and Space Administration (NASA; Gander, Myhre, Graeber, Andersen, and Lauber, 1989). Measures that were utilized for analysis in this paper included sleep onset and awake times, sleep duration, reported awakenings, sleep quality ratings, Stanford Sleepiness Scale (SSS) ratings (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973), and Positive and Negative Affect Schedule (PANAS) ratings (Watson, Clark, & Tellegen, 1988). Sleep quality ratings (SQR) were obtained upon arising. SSS and PANAS ratings were obtained at 0hr, 2hr 45min, 4hr 45min, and 7hr 30min into the shift. SSS ratings were also collected for the drive home from each shift.

Physiological Monitor

The Series 2000 Minilogger™ ambulatory physiological monitor (MiniMitter™ Co., Inc., P.O. Box 3386, Sunriver, OR 97707) was used to measure the inter-beat-interval (IBI) of heart beats, core body temperature, wrist activity, and ambient light. Sensors included: 1) a Polar™ Chest Band for measuring

IBI, 2) a Yellow Springs Instruments™ flexible rectal temperature sensor, 3) a small wrist activity monitor, and 4) an ambient light sensor. All of these channels were direct wired to the Minilogger. Temperature, activity, and light measures were recorded in 1-minute epochs.

Design and Data Analysis

The design of the study was a mixed-model, repeated measures design where schedule rotation represented the between-groups variable, and week, day, session, and/or sleep period represented the within-groups variables. The majority of analyses utilized the General Linear Model for Repeated Measures procedure, in addition to post-hoc comparisons using the Bonferroni adjustment for multiple comparisons. In the case of missing data, values were replaced with the comparable shift data for each participant. For example, if the sleep quality rating was missing for a given participant on the first early-morning shift in the first week of shiftwork, this rating was replaced with that participant's rating for the first early-morning shift in the second week of shiftwork.

Subjective Sleep Data

Sleep duration was calculated as reported sleep duration minus reported awakenings of 10 minutes or longer. In addition, 21 corrections were made when reported sleep duration was clearly miscalculated based on the reported sleep onset and awake times (e.g., when subjects miscalculated sleep duration by 1 or 2 hours). Daily logs from all 28 participants were included in the analysis, with only 1 missing data point during the 2 weeks of shiftwork.

Actigraphy Sleep Data

Data from the wrist activity sensor were scored utilizing the Action-W™ version 2.0 software. Bad data, including missing data due to removal of the wrist monitor, as well as sensor or battery failure, were removed from each record. These times were verified using logbook reports and logged information regarding known failures of the device. The "auto set down interval" function was used as an initial sleep-scoring tool based on the Cole-Kripke (1988) re-scoring algorithm. "Down times" were then altered as necessary so that work times were not incorrectly scored as sleep, and sleep periods that were separated by brief awakenings were combined. Records from 6 participants could not be scored. Four of these records contained too much missing data due to device failures. One record could not be matched reliably to self-reported "logger off" times, leaving the scoring open to excessive error. Another record seemed to suffer from a mix of problems, including subject non-compliance, two failed/broken sensors, dead batteries, and mixed up channel plug-ins. Of the 22 records that were included in the analysis, there were 13 missing sleep periods during the 2 weeks of shiftwork.

Subjective Ratings

Responses to the SQR were re-scored so that high scores on each question indicated good sleep. Responses to all 4 questions were summed for a total SQR with a range of possible scores from 4 to 20. There were 3 missing sleep quality ratings. Although SSS ratings only ranged from 1 to 7, these were analyzed with MANOVA because of a lack of non-parametric methods for analyzing mixed-model designs. There were 41 missing values for the SSS ratings, which represented 2.9% of the 1400 ratings included in the analysis. About half of the missing ratings were for the end of the shift or the drive home. Scores for the negative affect (NA) and positive affect (PA) portions of the PANAS were calculated by summing the ratings for all the NA and PA adjectives. There were 5 missing PA and NA scores out of 1,120 ratings (0.4%).

RESULTS

The results of the analyses for the following dependent measures are presented: subjective sleep duration, scored sleep duration, SQR, SSS, and PANAS ratings. Each of the dependent measures was assessed in terms of potential sleep/wake cycle disruption associated with clockwise and counter-clockwise shift rotation schedules. Descriptive statistics for each variable are included in Appendix A. To ensure that the groups were not different at baseline, statistical comparisons of the Day 4 (Thursday) data were calculated for each measure. These analyses revealed no significant findings, indicating that the 2 groups were not different from each other at baseline. Likewise, the average WAIS-R score for those in the clockwise condition (M = 109.5, sd = 4.4) was not statistically different from those in the counter-clockwise condition (M = 111.1, sd = 6.0).

Self-reported Sleep Duration (Logbooks)

A 2 (week) x 6 (sleep period) x 2 (rotation condition) between-groups, repeated measures MANOVA was conducted on subjective sleep duration for the sleep periods before the 5 shifts and the first recovery night of sleep following each workweek. To accommodate the mix of night and naptime sleep obtained before the midnight shift, the night sleep obtained by the counter-clockwise group before the second early-morning shift (M_{week2} = 5.8h; M_{week3} = 6.1h) was combined with the nap before the midnight shift (M = 2.2h for both weeks). Likewise, the night sleep obtained by the clockwise group before the midnight shift (M_{week2} = 7.0h; M_{week3} = 7.4h) was combined with the daytime nap before the midnight shift (M_{week2} = 1.1h; M_{week3} = 0.6h). The analysis revealed only a significant main effect for sleep period, $F(5, 22) = 52.5$, $p = .000$ (Figure 1). Post-hoc comparisons using a Tukey critical value revealed that sleep duration before the two early-morning shifts (M = 5.0h and 5.6h) was significantly shorter than before the two afternoon shifts (M = 7.9h and 7.5h), the midnight shift (M = 8.1h), or the recovery sleep period following the workweek (M = 8.4h). In addition, sleep duration before the first early-morning shift was significantly shorter than before the second early-morning shift. Subsequent analyses revealed a significant effect for age, $F(1,26) = 7.2$, $p = .013$, indicating that participants under 40 (M = 6.8h) received significantly less sleep than those over 40 (M = 7.4h). Analysis of the full model with age as a covariate did not result in different results than those reported earlier.

Scored Sleep Duration (Actigraphy)

A 2 (week) x 6 (sleep period) x 2 (rotation condition) between-groups, repeated measures MANOVA was conducted on sleep duration data scored from wrist actigraphy for the sleep periods before the 5 shifts and the first recovery night of sleep following each workweek. Again, night and naptime sleep periods before the midnight shift were combined, so that the night sleep obtained by the counter-clockwise group before the second early-morning shift (M_{week2} = 6.5h; M_{week3} = 6.6h) was combined with the nap before the midnight shift (M_{week2} = 2.8h; M_{week3} = 2.9h). In addition, the night sleep obtained by the clockwise group before the midnight shift (M_{week2} = 7.5h; M_{week3} = 8.2h) was combined with the nap before the midnight shift (M_{week2} = 1.7h; M_{week3} = 1.3h). The results revealed only a significant main effect for sleep period, $F(5, 16) = 40.9$, $p = .000$ (Figure 2). Post-hoc comparisons revealed that sleep duration before the 2 early-morning shifts (M = 5.6h and 6.5h) was significantly shorter than before the 2 afternoon shifts (M = 8.2h and 8.0h), the midnight shift (M = 9.3h) and the recovery sleep period following the workweek (M = 8.6h). In addition, sleep duration before the first early-morning shift was significantly shorter than before the second early-morning shift, and sleep before the second afternoon shift was significantly shorter than the combined sleep before the midnight shift. Although sleep duration for the scored sleep was generally longer (by an average of 36 minutes) than subjectively reported sleep duration, the pattern of sleep duration was similar, and the statistical results were the same.

Subsequent analyses revealed a significant effect for age, $F(1, 20) = 6.8$, $p = .017$, indicating that participants under 40 received significantly less sleep (M = 7.3h) than participants over 40 (M = 8.1h) as found with the reported sleep durations from the logbooks. A reduced sample size and unequal representation of age and rotation condition (n = 4 clockwise/under 40; n = 5 clockwise/over 40; n = 7 counter-clockwise/under 40; n = 6 counter-clockwise/over 40) due to missing data may have resulted in less power for the analysis of the full model with age as a covariate. As a result, the main effect for sleep period was not significant with the MANCOVA analysis. Examination of mean sleep duration by rotation condition and age for each sleep period, however, revealed that both age groups within both rotation conditions received

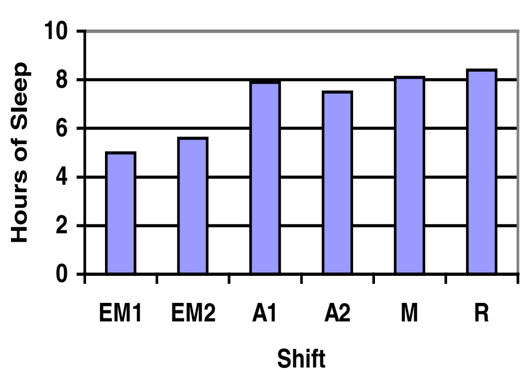

Figure 1. Subjective Sleep Duration

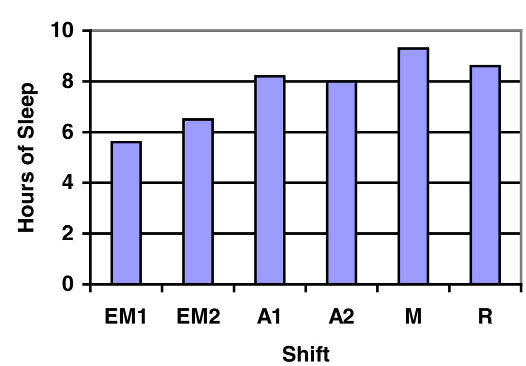

Figure 2. Scored Sleep Duration

EM-Early Morning shift A-Afternoon shift, M-Midnight shift, R-Recovery night substantially less sleep before the 2 early-morning shifts than before any other shift in the schedule (See Table A3 in Appendix A).

Sleep Onset and Wake Up Times

A 2 (week) x 5 (sleep period) x 2 (rotation condition) between-groups, repeated measures MANOVA was conducted on sleep onset and wake up times from the scored wrist activity data for the sleep periods before the 2 early-morning and afternoon shifts and the first recovery night of sleep following each work-week. The results for sleep onset time revealed a significant main effect for sleep period, $F(4, 17) = 16.0$, $p = .000$. Sleep/work cycles for the clockwise and counter-clockwise shift rotations are presented in Figures 3 and 4, with the last 3 days of the day shift week and the average sleep times for both shiftwork weeks. Post-hoc comparisons revealed that sleep onset before the first early-morning shift (M = 22:59) was significantly later than before the second early-morning shift (M = 22:12). Sleep onset time before the second early-morning shift was significantly earlier than before the afternoon shifts and recovery sleep period (M = 23:33, 23:53, and 23:45). In addition, sleep onset before the first early-morning shift was significantly earlier than before the second afternoon shift. The MANOVA for wake up time also revealed a significant main effect for sleep period, $F(4,17)$ =

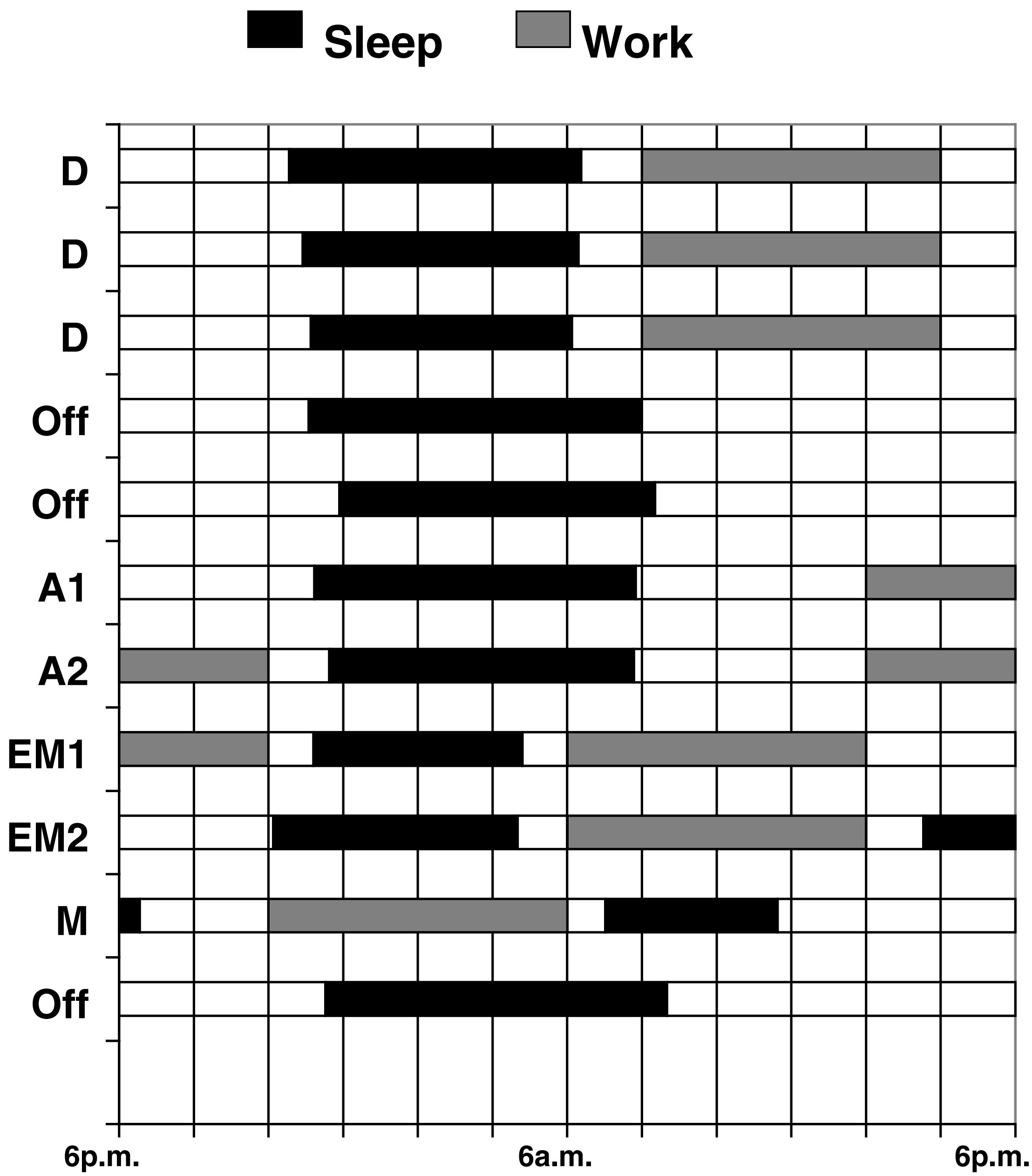

Figure 3. Sleep/Work Cycle for Counter-Clockwise Rapidly Rotating Shift Schedule
D-Day shift, EM-Early Morning shift, A-Afternoon shift, M-Midnight shift

47.4, p = .000. As expected, post-hoc comparisons revealed that awake time was significantly earlier before the two early-morning shifts (M = 04:39 and 04:40) than before the afternoon shift and recovery sleep periods (M = 07:53, 07:54, and 08:34). Subsequent analyses indicated that there were no age effects for sleep onset or awake time.

Napping

Table 3 presents a cross-tabulation of the frequency of naps taken before the midnight shifts in the study. Clearly, a much larger proportion of individuals in the counter-clockwise rotation (79%) took a nap before the midnight shift in week 2 than individuals in the clockwise rotation (57%). This pattern was even more

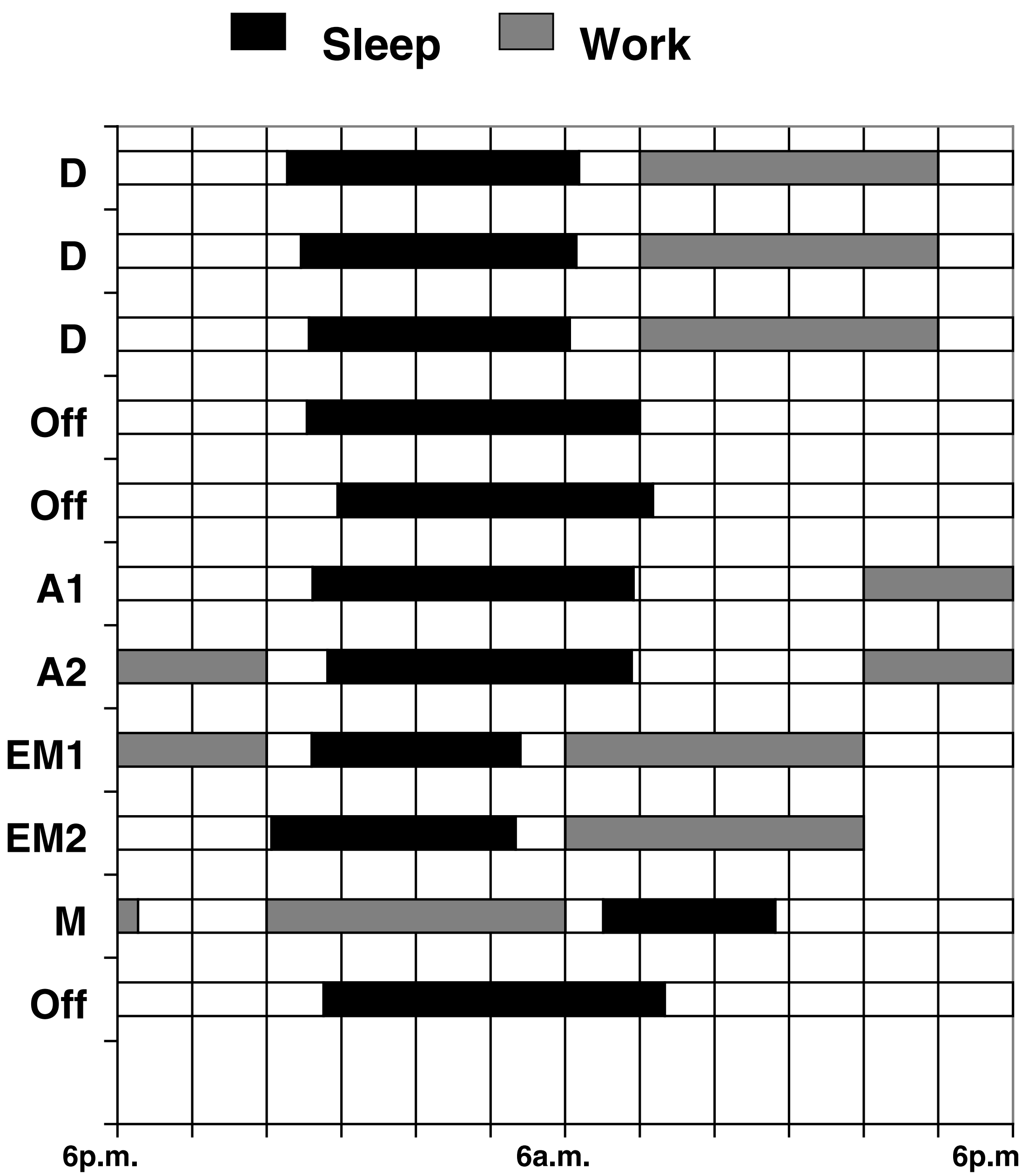

Figure 4. Sleep/Work Cycle for Counter-Clockwise Rapidly Rotating Shift Schedule
D-Day shift, EM-Early Morning shift, A-Afternoon shift, M-Midnight shift

Table 3.

Frequency of Napping Before the Midnight Shift

	Week 2		**Week 3**	
Rotation Condition	Nap	No Nap	Nap	No Nap
Clockwise	8	6	5	9
Counter-Clockwise	11	3	13	1

exaggerated in week 3, with 93% of the counter-clockwise condition taking a nap before the midnight shift, compared with only 36% of the clockwise rotation. Of those who took naps, average reported nap length in the clockwise condition was 1.9h and 1.8h for weeks 2 and 3, respectively. And, of those who took naps in the counter-clockwise condition, the average reported nap length was 2.8h and 2.3h for weeks 2 and 3, respectively.

Sleep Quality Ratings

A 2 (week) x 5 (sleep period) x 2 (rotation condition) between-groups, repeated measures MANOVA was conducted on SQR for the sleep periods before the 2 early-morning and afternoon shifts and the first recovery night of sleep following each workweek. The results revealed a significant main effect for sleep period, $F(4,23) = 8.1$, $p = .000$ (Figure 5). Post-hoc comparisons indicated that sleep quality ratings for the sleep period before the first early-morning shift ($M = 12.6$) were significantly lower than those for the sleep periods before the afternoon shifts and the recovery sleep ($M = 14.8$, 14.6, and 15.8). Sleep quality ratings for the second early-morning shift ($M = 13.8$) were significantly lower than the recovery sleep period ($M = 15.8$).

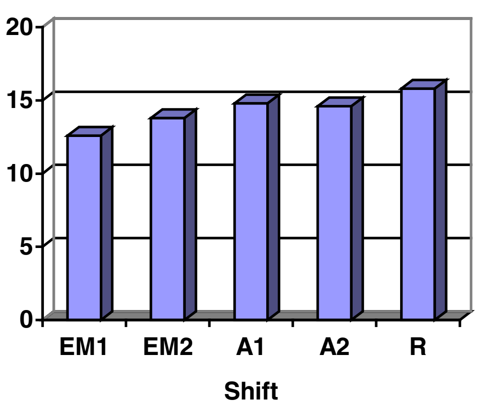

Figure 5. Sleep Quality Ratings
EM1-1st early-morning shift M2-2nd early-morning shift A1-1st afternoon shift A2-2nd afternoon shift M-midnight shift R-Recovery night

Stanford Sleepiness Scale Ratings

A 2 (week) x 5 (shift) x 5 (rating) x 2 (rotation condition) between-groups, repeated measures MANOVA was conducted on SSS ratings over the workday and for the drive home for the 2 shiftwork weeks. The results revealed a significant shift by rating interaction, $F(16, 11) = 7.6$, $p = .001$. This relationship is depicted in Figure 6 and shows that ratings of sleepiness increased across the workday for all shifts but particularly so for the midnight shift. Tukey multiple comparisons were conducted for ratings on the midnight shift and for ratings at the beginning, end, and drive home from each shift. On the midnight shift, sleepiness was significantly higher at the end of the shift ($M = 5.6$) than any of the other ratings, which ranged from 2.6 to 4.5. In addition, the third rating of the shift ($M = 4.0$) and the drive home ratings ($M = 4.5$) were higher than the first 2 ratings of the midnight shift ($M = 2.6$ and 3.0). Ratings at the beginning of the first early-morning shift ($M = 3.2$) were significantly higher than at the beginning of either of the afternoon shifts ($M = 2.0$ and 2.1). SSS ratings were significantly higher at the end of the midnight shift ($M = 5.6$) than at the end of any of the other shifts ($M = 3.0$, 3.6, 3.8, and 3.9). In addition, ratings were higher on the drive home from the midnight shift ($M = 4.5$) than on the drive home from any of the other shifts ($M = 2.9$, 3.0, 3.1, and 3.1).

A reduced model (2 weeks x 5 ratings x 2 rotation conditions) was subsequently analyzed for SSS ratings on the midnight shift to further investigate possible relationships on that shift. Results of the analysis revealed a significant week by rating by rotation condition interaction, $F(4,23) = 2.8$, $p = .037$. Simple effects analysis revealed that individuals in the counter-clockwise rotation reported significantly higher ratings

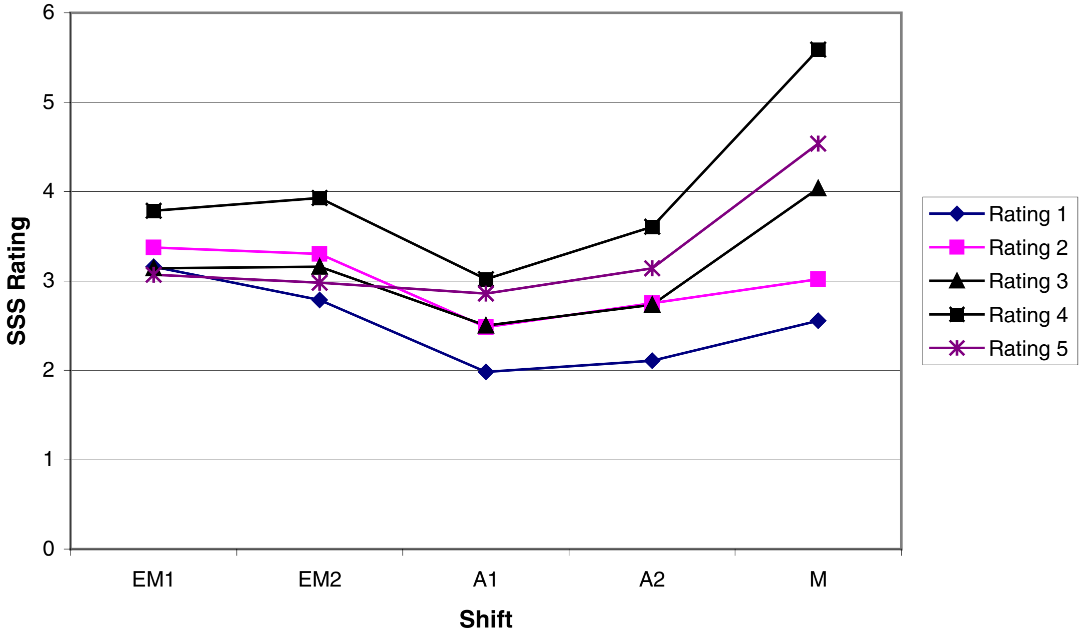

Figure 6. SSS Ratings. Shift by Rating Interaction
EM1-1st early-morning shift EM2-2nd early-morning shift A1-1st afternoon shift A2-2nd afternoon shift M-midnight shift

at the end of the midnight shift during the first week of shiftwork ($M = 6.1$) than individuals in the clockwise rotation ($M = 4.9$), $F(1,26) = 4.8$, $p = .038$. There was no difference between rotation conditions, however, at the end of the midnight shift during the second week of shiftwork (Figure 7).

Positive and Negative Affect Schedule

A 2 (week) x 5 (shift) x 4 (rating) x 2 (rotation condition) between-groups, repeated measures MANOVA was conducted on negative affect (NA) and positive affect (PA) ratings over the workday for the 2 shiftwork weeks. Results of the NA ratings revealed no significant effects. On the other hand, results of the PA ratings revealed main effects for Shift, $F(4,23) = 10.6$, $p = .000$, and Rating, $F(3,24) = 12.1$, $p = .000$. Post-hoc comparisons for Shift (Figure 8) indicated that ratings of PA on the first afternoon shift ($M = 21.8$) were significantly higher than ratings of PA on the early-morning shifts ($M = 19.0$ and 19.1) or the midnight shift ($M = 17.2$). In addition, PA ratings

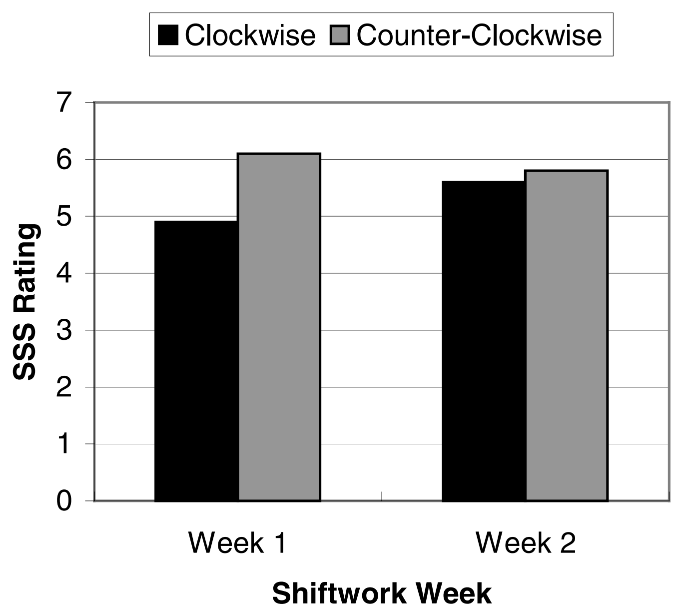

Figure 7. SSS Ratings for the End of the Midnight Shift

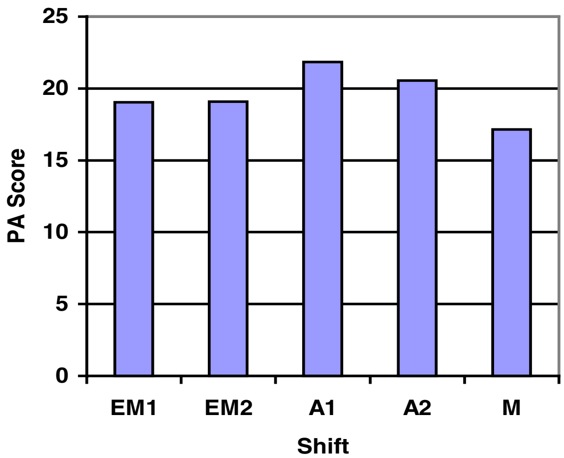

Figure 8. Positive Affect Ratings by Day
EM1-1st early-morning shift EM2-2nd early-morning shift A1-1st afternoon shift
A2-2nd afternoon shift M-midnight shift

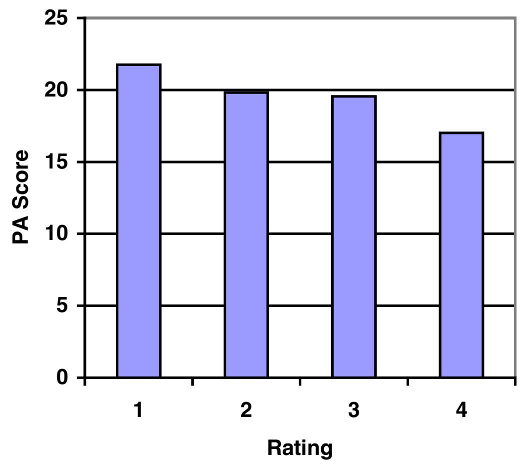

Figure 9. Positive Affect Ratings by Rating Time

on the second afternoon shift (M = 20.5) were higher than those on the midnight shift. Post-hoc comparisons for Rating (Figure 9) indicated that the first PA rating of each shift (M = 21.8) was significantly higher than ratings 2, 3, or 4 (M = 19.8, 19.6, and 17.0, respectively). In addition, PA ratings at the end of each shift were significantly lower than ratings 1, 2, or 3.

DISCUSSION

This study represents one of the first experimentally controlled investigations of direction of rotation in rapidly rotating shift schedules. The purpose of this paper was to directly compare the sleep and subjective ratings of individuals working clockwise and counter-clockwise, rapidly rotating shift schedules to test the hypothesis that the clockwise rotation results in better outcomes. Put simply, rotation condition did not play a significant role in the results of any of these measures. Instead, results of the study indicated that sleep duration, timing, and quality were dependent only on sleep period and that subjective sleepiness was dependent on both shift and rating time.

Sleep Measures

Results of the study were similar to past research on the 2-2-1 (Della Rocco, Cruz, & Schroeder, 1995) and other schedules (Folkard, 1989) indicating that sleep duration is dramatically reduced before early-morning shifts, compared with afternoon shifts. It was expected that individuals in the clockwise condition would obtain more sleep before the first early-morning shift than those in the counter-clockwise condition because of the quick-turn-around in the counter-clockwise rotation. The truth, however, was that the first early-morning shift worked by the clockwise group suffered from a "weekend effect," as participants continued to go to bed as late as they had all weekend and were forced to get up early for the early-morning shift, thereby reducing sleep duration. Indeed, both groups reported about 5 hours of sleep before the first early-morning shift in their respective rotations.

The direct comparison of clockwise and counter-clockwise rotations led us to view the sleep obtained before the midnight shift differently than in the past. Specifically, it is true that the clockwise rotation has an "extra" night of sleep before the midnight shift; however, this night of sleep is followed by a full day of time spent awake for the most part before participants go to work on the midnight shift. On the other hand, sleep obtained before the second early-morning shift in the counter-clockwise rotation is followed by a day of work and a fairly significant nap taken by the majority of people working the schedule. In the past, we would have focused only on the nap before the midnight shift. Now, it is clear that the night of sleep, while reduced due to the early-morning shift, still contributes to the sleep obtained before the midnight shift and that it is unfair to view the nap before the midnight shift as the only sleep period obtained before that shift. Indeed, our findings indicate that, when naps were combined with the major sleep period, there was no difference between the rotation conditions in the amount of sleep obtained before staying up all night.

The effect of the entire workweek might also be considered in terms of the amount of sleep obtained on the first night of sleep following the midnight shift (i.e., the recovery sleep period). Both groups obtained more than 8 hours of sleep during the recovery sleep period. This amount of sleep was not significantly longer than those observed before the afternoon shifts and was not statistically different between the clockwise and counter-clockwise conditions, which indicates that direction of rotation did not differentially affect fatigue or sleep loss.

While tolerance to shiftwork is generally considered to decline with increasing age (Akerstedt & Torsvall, 1981; Monk & Folkard, 1985), one interesting finding from this study was that participants over 40 received significantly more sleep during the shiftwork weeks than participants under 40. Although there was no significant effect of age in the scored sleep onset and wake up time data, this may have been due to reduced power in the design because of reduced and unequal samples. An examination of the means for rotation condition and age, however, revealed that the differences in sleep duration appeared to be due to later bedtimes before the early-morning shifts and earlier wake-up times before the afternoon shifts and on the recovery sleep periods for the under-40 age group.

Subjective Ratings

Subjective ratings, like the results of sleep duration and timing, revealed no differences between the rotation conditions. Instead, early-morning shifts, particularly the first one of the workweek, were once again identified as problem areas. Sleep quality was significantly lower before the first early-morning shift than before the evening or recovery sleep periods. In addition, ratings of sleepiness were significantly higher at the beginning of the first early-morning shift than at the beginning of the afternoon shifts. And, positive affect was significantly lower on the early-morning shifts than on the first evening shift.

The midnight shift poses particular problems for maintaining performance and alertness during the night because it requires people to work against the biological clock (Cruz & Della Rocco, 1995; Della Rocco & Cruz, 1995). As expected, participants reported being significantly sleepier at the end of the midnight shift and on the drive home from the midnight shift than on any other shift. The average rating for the end of the midnight shift corresponded most closely to the scale response, "Sleepy, woozy; prefer to be lying down; fighting sleep," while the average rating for the drive home from the midnight shift corresponded most closely to the scale response, "Foggy; slowed down; beginning to lose interest in remaining awake." These results clearly demonstrate the need for effective counter-measures for the sleepiness experienced on the midnight shift and during what can be very dangerous, early morning rush-hour traffic.

In addition, analysis of sleepiness ratings focusing on the midnight shift revealed the only evidence in these data to indicate that the 2 conditions differed. Specifically, individuals in the counter-clockwise rotation reported being sleepier at the end of the midnight shift than individuals in the clockwise rotation in the first week of shiftwork. The fact that this difference disappeared in the second week of shiftwork is likely because the counter-clockwise group obtained an average of 20 minutes more sleep before the midnight shift in the second week of shiftwork than in the first. This sleep was obtained not during the nap before the midnight shift but, rather, during the night before the second early-morning shift. This may indicate that in as short as 2 weeks of shiftwork, individuals began to incorporate coping strategies in the counter-clockwise rotation to increase sleep and thereby reduce their sleepiness on the midnight shift.

SUMMARY

The results from this study conflict with the bulk of the literature regarding direction of shift rotation, but support more recent suggestions that there may be fewer differences in these kinds of schedules than was once thought (Tucker, Smith, Macdonald, & Folkard, 2000). They also support the theoretical work reported by Turek (1986) some years earlier that sleep patterns and circadian rhythms may be similarly affected by clockwise and counter-clockwise shift rotations. It is also important to note that most of the literature regarding direction of shift rotation has involved more slowly rotating shift schedules than those investigated in this study. While individual results of a non-significant nature generally fail to reveal or add much to the scientific understanding of a relationship, evidence is growing that direction of rotation, particularly in rapidly rotating shift schedules, does not affect outcomes such as sleep and subjective ratings of fatigue. Replications of this kind of research in the laboratory and in field research are needed to make reliable conclusions with regard to direction of shift rotation.

While the findings from this study are relevant to real-world shiftwork scheduling practices, one major limitation of this study is that it only represents short-term adaptation to the clockwise and counter-clockwise rotation schedules investigated. It is not clear that sleep patterns would be similar for experienced shiftworkers, although the results for the counter-clockwise condition are consistent with the results obtained in other studies of FAA air traffic controllers in the field (Cruz & Della Rocco, 1995; Cruz, Della Rocco, & Hackworth, 2000). Specifically, the results from this study indicate that the counter-clockwise shiftwork schedules currently in use by air traffic controllers in the U.S. would not likely be improved by reversing the direction of rotation. In addition, it is clear that two major problem areas in both clockwise and counter-clockwise rapidly rotating shift schedules are early-morning and midnight shifts—areas that should receive more study in the future.

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APPENDIX A

Tables of Descriptive Statistics for Study Measures

Table A1
Descriptive Statistics for Self-Reported Sleep Duration from Logbooks

Shift/Sleep Period	Clockwise Rotation (n=14)				Counter-Clockwise Rotation (n=14)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1	5.1	1.1	4.9	1.2	5.0	0.8	4.9	1.0
Early Morning 2	5.4	0.9	5.1	1.0	5.8	0.8	6.1	0.9
Afternoon 1	7.7	1.4	7.7	1.2	8.2	1.2	7.8	1.5
Afternoon 2	7.2	1.3	7.5	1.1	7.9	0.9	7.5	1.3
Midnight	7.0	1.4	7.4	0.8	--	--	--	--
Nap before Midnight	1.1	1.7	0.6	1.1	2.2	1.6	2.2	1.4
Nap after mid	4.9	2.1	5.4	1.8	4.3	1.6	4.3	1.6
Recovery	8.3	1.7	8.3	2.1	8.6	1.7	8.4	1.4

Table A2
Descriptive Statistics for Scored Sleep Duration from Wrist Actigraphy

Shift/Sleep Period	Clockwise Rotation (n=9)				Counter-Clockwise Rotation (n=13)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1	5.7	1.6	5.6	1.2	5.6	0.5	5.5	0.7
Early Morning 2	6.6	0.9	6.2	2.1	6.5	0.4	6.6	0.8
Afternoon 1	7.9	1.5	7.8	0.9	8.7	1.4	8.4	1.6
Afternoon 2	7.8	1.3	7.8	1.2	8.2	0.8	7.9	1.2
Midnight	7.5	1.8	8.2	1.6	--	--	--	--
Nap before Midnight	1.7	1.8	1.3	1.4	2.8	1.6	2.9	1.3
Nap after mid	4.5	2.5	4.3	1.4	4.5	1.6	4.1	1.7
Recovery	8.3	1.8	8.5	1.7	8.9	1.6	8.9	1.0

Table A3
Descriptive Statistics for Scored Sleep Duration by Age and Rotation Condition

Shift/Sleep Period	Clockwise Rotation (n=9)				Counter-Clockwise Rotation (n=13)			
	<40 yrs old (n=4)		>40 yrs old (n=5)		<40 yrs old (n=7)		>40 yrs old (n=6)	
Week 2	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1	5.3	2.1	6.0	1.3	5.6	0.5	5.5	0.5
Early Morning 2	6.3	0.8	6.8	1.0	6.4	0.4	6.6	0.4
Afternoon 1	7.5	2.0	8.3	1.0	8.2	1.5	9.2	1.1
Afternoon 2	7.2	1.2	8.3	1.4	8.1	1.0	8.4	0.5
Midnight	8.7	1.1	9.7	2.0	8.7	1.6	8.9	2.3
Recovery	6.9	0.8	9.3	1.6	8.6	2.0	9.2	1.0
Week 3								
Early Morning 1	5.5	1.4	5.7	1.2	5.4	0.7	5.7	0.6
Early Morning 2	5.4	1.1	6.8	2.6	6.2	0.7	7.0	0.6
Afternoon 1	7.9	1.0	7.7	0.9	7.9	1.6	9.1	1.4
Afternoon 2	7.2	0.9	8.3	1.2	7.3	1.1	8.7	0.9
Midnight	8.6	1.1	10.3	2.9	8.6	1.9	10.6	0.8
Recovery	8.4	1.5	8.6	2.1	8.9	1.0	9.0	1.2

Table A4
Descriptive Statistics for Sleep Onset Time

Shift/Sleep Period	Clockwise Rotation (n=9)				Counter-Clockwise Rotation (n=13)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1	22:32	01:47	23:01	01:22	23:13	00:22	23:10	00:37
Early Morning 2	22:03	01:03	22:32	02:11	22:16	00:36	21:59	00:55
Afternoon 1	23:51	02:01	23:51	01:59	23:26	01:04	23:04	01:00
Afternoon 2	00:06	01:05	00:11	01:01	23:34	00:39	23:42	00:43
Midnight	00:18	01:11	00:01	01:30	--	--	--	--
Nap before Midnight	15:55	02:45	15:11	02:53	15:31	01:00	15:32	01:05
Nap after mid	06:48	00:21	06:41	00:20	06:57	00:32	07:05	00:31
Recovery	23:50	02:06	00:08	01:47	23:21	01:41	23:41	01:25

Table A5
Descriptive Statistics for Awake Time

Shift/Sleep Period	Clockwise Rotation (n=9)				Counter-Clockwise Rotation (n=13)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1	04:24	00:32	04:41	00:24	04:48	00:25	04:46	00:26
Early Morning 2	04:39	00:22	04:42	00:22	04:42	00:28	04:36	00:30
Afternoon 1	07:59	01:32	07:47	01:34	08:13	01:26	07:33	01:27
Afternoon 2	08:00	01:37	08:02	01:34	07:53	00:45	07:41	01:08
Midnight	07:56	01:56	08:02	01:39	--	--	--	--
Nap before Midnight	18:09	02:32	17:32	02:08	18:37	01:35	18:30	01:37
Nap after mid	12:04	02:02	10:45	01:27	11:43	01:21	11:32	01:00
Recovery	08:13	01:53	08:45	01:52	08:36	01:09	08:43	00:56

Table A6
Descriptive Statistics for Sleep Quality Ratings

Shift/Sleep Period	Clockwise Rotation (n=14)				Counter-Clockwise Rotation (n=14)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1	12.7	4.8	12.9	4.3	12.3	3.1	12.5	2.7
Early Morning 2	14.0	3.4	13.7	3.8	13.1	3.5	14.4	3.0
Afternoon 1	14.4	2.5	14.5	3.9	14.6	2.8	15.9	2.8
Afternoon 2	14.3	3.6	14.9	2.9	15.1	2.4	13.9	3.0
Recovery	14.7	3.0	15.6	2.7	16.1	2.4	16.9	2.5

Table A7
Descriptive Statistics for Stanford Sleepiness Scale Ratings

Shift	Clockwise Rotation (n=14)				Counter-Clockwise Rotation (n=14)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1								
Rating 1	2.9	1.1	3.3	1.4	3.0	0.7	3.4	0.9
Rating 2	3.0	1.3	3.3	1.4	4.0	1.5	3.2	1.6
Rating 3	2.6	1.1	3.3	1.1	3.1	1.1	3.6	1.7
Rating 4	3.8	1.6	3.9	1.6	3.7	1.7	3.7	1.7
Rating 5	2.7	1.1	3.4	1.3	3.0	1.3	3.1	1.4
Early Morning 2								
Rating 1	2.8	1.5	2.9	1.3	2.8	0.9	2.6	0.7
Rating 2	3.4	1.5	3.4	1.8	3.1	0.9	3.4	1.2
Rating 3	3.1	1.5	3.8	1.7	2.6	1.3	3.2	1.3
Rating 4	4.2	1.3	4.1	1.8	3.6	1.2	3.7	1.5
Rating 5	3.0	1.5	3.1	1.6	2.8	1.1	3.0	1.0
Afternoon 1								
Rating 1	1.9	1.0	2.1	1.3	2.1	0.9	1.7	0.7
Rating 2	2.3	1.1	2.3	1.1	2.6	0.9	2.8	1.3
Rating 3	2.4	1.3	2.2	1.4	2.8	1.1	2.6	1.4
Rating 4	2.9	1.4	3.1	1.5	3.1	1.2	2.9	1.1
Rating 5	2.8	1.5	2.9	1.3	2.9	1.0	2.9	1.2
Afternoon 2								
Rating 1	2.4	1.6	1.9	1.0	2.2	1.1	2.1	1.1
Rating 2	2.9	1.7	2.8	1.2	2.9	1.7	2.4	1.3
Rating 3	2.8	1.4	3.0	1.6	2.8	0.9	2.4	1.2
Rating 4	3.5	1.7	3.7	1.7	3.5	1.2	3.7	1.3
Rating 5	3.3	1.3	3.1	1.4	3.1	1.1	3.0	1.6
Midnight								
Rating 1	2.4	1.4	2.1	1.4	2.6	1.2	3.0	0.9
Rating 2	3.4	1.5	2.9	1.4	3.0	1.2	2.8	1.1
Rating 3	4.2	1.8	3.9	1.6	4.1	1.4	4.0	1.0
Rating 4	4.9	1.7	5.6	1.7	6.1	1.0	5.8	1.3
Rating 5	4.1	1.9	4.2	1.8	4.9	1.2	5.0	1.3

Table A8
Descriptive Statistics for Negative Affect Ratings

Shift	Clockwise Rotation (n=14)				Counter-Clockwise Rotation (n=14)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1								
Rating 1	11.5	2.3	12.1	4.8	10.2	0.6	10.7	1.1
Rating 2	11.4	2.2	11.9	4.8	10.3	0.6	10.6	0.9
Rating 3	10.6	1.6	11.5	3.9	10.4	0.8	11.1	2.0
Rating 4	11.1	1.8	11.7	4.5	10.2	0.6	11.6	2.8
Early Morning 2								
Rating 1	10.9	2.5	11.3	3.7	10.3	0.6	10.1	0.4
Rating 2	12.1	3.9	11.4	3.7	10.1	0.5	10.4	0.8
Rating 3	13.7	10.2	10.3	3.4	10.2	0.8	10.1	0.4
Rating 4	12.2	4.1	11.1	3.7	10.1	0.3	10.4	1.1
Afternoon 1								
Rating 1	10.7	2.1	11.0	4.2	10.4	1.3	10.1	0.5
Rating 2	10.8	2.4	12.1	4.2	10.0	0.0	10.2	0.8
Rating 3	11.1	2.6	11.5	4.0	10.1	0.4	10.0	0.0
Rating 4	11.2	2.6	11.4	3.7	10.5	1.3	10.1	0.3
Afternoon 2								
Rating 1	11.6	4.8	11.0	3.2	10.4	1.1	10.4	1.1
Rating 2	11.5	4.5	10.8	2.4	10.1	0.4	10.4	0.9
Rating 3	11.9	4.6	11.0	2.9	10.3	0.6	10.2	0.6
Rating 4	11.7	4.3	11.2	2.8	10.1	0.4	10.6	2.1
Midnight								
Rating 1	11.2	3.4	11.2	3.2	10.2	0.4	10.1	0.4
Rating 2	11.4	4.0	11.2	3.4	10.0	0.0	10.1	0.4
Rating 3	11.7	4.0	11.2	2.9	10.3	0.6	10.1	0.4
Rating 4	11.9	4.0	11.5	3.0	10.3	0.6	10.5	1.6

Table A9
Descriptive Statistics for Positive Affect Ratings

Shift	Clockwise Rotation (n=14)				Counter-Clockwise Rotation (n=14)			
	Week 2		Week 3		Week 2		Week 3	
	mean	sd	mean	sd	mean	sd	mean	sd
Early Morning 1								
Rating 1	22.4	8.4	20.5	8.8	18.4	6.6	16.9	7.0
Rating 2	21.2	7.5	21.9	9.5	15.9	5.3	17.3	9.4
Rating 3	23.1	9.6	21.0	8.8	18.4	7.2	17.1	9.8
Rating 4	19.4	9.2	17.4	8.0	18.2	11.7	15.6	6.7
Early Morning 2								
Rating 1	22.3	8.2	20.0	6.4	19.4	6.3	18.8	6.6
Rating 2	21.9	9.6	20.6	8.7	19.2	8.2	16.4	4.4
Rating 3	20.8	8.2	19.9	9.5	19.2	8.7	17.9	7.5
Rating 4	17.0	7.5	18.6	8.8	16.7	8.6	16.6	8.0
Afternoon 1								
Rating 1	26.9	7.7	25.2	10.6	22.8	6.5	23.0	9.9
Rating 2	23.3	7.3	22.9	9.7	19.8	6.5	18.4	4.1
Rating 3	23.6	8.1	23.9	11.6	20.8	9.3	20.4	9.0
Rating 4	23.3	9.0	17.3	7.1	18.1	7.6	20.0	8.3
Afternoon 2								
Rating 1	25.1	9.8	26.5	10.0	22.4	9.2	20.7	9.6
Rating 2	22.1	8.3	21.1	9.0	18.9	6.3	20.1	7.9
Rating 3	22.0	8.7	21.8	8.9	19.4	6.4	18.9	7.9
Rating 4	18.6	6.3	18.2	7.4	16.9	7.4	16.0	8.6
Midnight								
Rating 1	23.9	9.7	23.6	9.9	18.8	7.8	17.5	6.1
Rating 2	18.6	6.8	19.6	6.6	19.1	9.8	18.2	8.1
Rating 3	16.7	6.3	16.1	6.7	16.2	7.3	13.9	5.2
Rating 4	14.7	6.3	13.1	5.1	12.5	5.6	11.9	4.4