DOT/FAA/AM-95/12

Office of Aviation Medicine
Washington, D.C. 20591

Sleep Patterns in Air Traffic Controllers Working Rapidly Rotating Shifts: A Field Study

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April 1995

Final Report

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-95/12		

4. Title and Subtitle	5. Report Date
Sleep Patterns in Air Traffic Controllers Working Rapidly Rotating Shifts: A Field Study	April 1995
	6. Performing Organization Code
7. Author(s) Crystal E. Cruz and Pamela S. Della Rocco	8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, OK 73125	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency name and Address FAA Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, SW. Washington, DC 20591	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract

This study was part of a research program in shift work and fatigue in the Air Traffic Control (ATC) environment. The purpose of the study was to investigate three different shift schedules in use at ATC facilities with respect to potential disruption of the sleep/wake cycle. A straight day schedule of early morning shifts (i.e., beginning before 0800), and two variations of counterclockwise, rapidly rotating shift schedules, the 2-2-1 and 2-1-2, were analyzed in terms of total sleep time, asleep and awake times, and subjective ratings of sleep quality and sleepiness. Data were collected in daily logbooks by air traffic control specialists (ATCSs).

Total sleep time on the 2-2-1 schedule showed a characteristic decline from approximately 8 hours before the two afternoon shifts, to 5 hours before the two early morning shifts, to 2.4 hours before the midnight shift. Total sleep time on the 2-1-2 schedule decreased from 7.5-8 hours before the two afternoon shifts and one midday shift to approximately 6 hours before the two early morning shifts. Total sleep time on the straight day shift schedule was approximately 6 hours for each day of the week. The least amount of sleep was obtained before early morning shifts in all of the schedules and before the midnight shift in the 2-2-1 schedule. Disruptions in the timing of sleep were limited to changes in the timing of waking up associated with rotations into the early morning shifts for the 2-2-1 and 2-1-2 schedules and, of course, the afternoon sleep before the midnight shift. Neither subjective ratings of sleep quality or sleepiness were found to vary by schedule type. More "high" ratings of sleepiness on the drive home, however, were reported following the midnight shift than any other shift.

17. Key Words	18. Distribution Statement
Air Traffic Control Specialists, Shift Work, Sleep/Wake Cycle, Sleepiness, Sleep Quality	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	18	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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SLEEP PATTERNS IN AIR TRAFFIC CONTROLLERS WORKING RAPIDLY ROTATING SHIFTS: A FIELD STUDY

Shift work is an unavoidable condition in many industries that require 24-hour operation, including Air Traffic Control (ATC). Shift schedule designs with various characteristics have evolved among industries to accommodate shift work. Some of the major characteristics in shift schedule designs include permanent vs. rotating schedules, slow vs. rapid rotations, and delaying (clockwise) vs. advancing (counterclockwise) rotations (Knauth, 1993). Each kind of shift schedule system has its own set of benefits and problems.

Akerstedt (1990) reported that disturbed sleep is perhaps the most dramatic effect of shift work on any schedule. Sleep duration on the night and morning shifts is reduced by one to four hours in shift workers on rotating schedules. Sleep duration for day workers has been reported to be generally longer than for shift workers, with day workers getting about 7.5 to 8.5 hours of sleep per night, and shift workers getting about 5 to 7 hours of sleep per night (Anch, Browman, Mitler & Walsh, 1988).

Rapidly rotating schedule systems involve working no more than two or three consecutive days on the same shift. Many argue that in rapidly rotating schedule designs, delaying shift systems are to be preferred to advancing ones (Folkard, 1989; Knauth & Rutenfranz, 1982; Czeisler, Moore-Ede, & Coleman, 1982). A delaying system rotates in a clockwise fashion such that work start times are progressively later across the work week. An advancing system, on the other hand, rotates in a counterclockwise fashion such that work start times are progressively earlier across the work week. Delaying systems effectively stretch out the work week, while advancing schedules compress it.

The primary complaint against the counterclockwise rotation is that it results in "quick-turn-arounds" at each shift change, which require employees to return to work after a relatively short time off. These quick-turn-arounds are thought to result in shortened sleep periods and increased fatigue, and to be a major source of complaints among shift workers (Folkard, 1989, 1992). Delaying systems are purportedly better because the endogenous body clock has a circadian cycle length of approximately 25 hours making adaptation to delays easier (Rosa et al., 1990). Akerstedt (1990) and Barton and Folkard (1993) concede, however, that despite the many claims that a delaying system should be preferred to an advancing one, there is very little empirical evidence of this. Turek (1986) suggested that sleep would be disrupted similarly (advanced once, delayed once, and not changed once) regardless of whether the shift rotation involved a delay or an advance. Researchers have suggested that maintaining consistent timing of sleep and wakefulness may be more important than quantity of sleep (Anch, Browman, Mitler & Walsh, 1988; Taub & Berger, 1973). Therefore, it is important to examine work schedules as they affect sleep timing.

Air Traffic Control Specialists (ATCSs) work relatively unique variations of counterclockwise, rapidly rotating-schedules. This circumstance provided an opportunity to examine the interaction of schedule characteristics and sleep patterns. The schedules in use at ATC facilities have relatively recently been modified, in some cases, to allow for 9- or even 10-hour days as part of an alternate work schedule. Because of the safety-related nature of ATC, and potential problems associated with rotating schedules (Wilkinson, 1992), it is important to understand the effects of these schedules on sleep.

Some data were available on one of the unique shift schedules in use at ATC facilities known as the "2-2-1." The 2-2-1 is a schedule of two afternoon shifts followed by two morning shifts followed by a night shift (Price & Holley, 1990). A characteristic sleep pattern has been reported for the 2-2-1 that has generally been shown to result in reductions in sleep duration across the work week and to result in less sleep, per day, on the average than a "straight-five"

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schedule i.e., weekly 5-day rotation of day, afternoon, and night shifts (Saldivar, Hoffmann, & Melton, 1977). Schroeder, Rosa, and Witt (1995) found that sleep duration was greatest before the first afternoon shift (8.35 hours), declined to 5.75 hours before the second day shift, and fell to 3.75 hours before the night shift. In a laboratory study investigating the 2-2-1, Della Rocco and Cruz (1995) found a similar pattern of decline in total sleep time across the five days of the 2-2-1 schedule from 7.6 and 6.4 hours prior to the two afternoon shifts to 5.8 and 6.6 hours prior to the two morning shifts to 3.7 hours prior to the night shift. In addition, the data in the lab-based study indicated that the sleep/wake cycle was disrupted on the 2-2-1 as compared to a straight day schedule. The only significant sleep loss in the schedule occurred just prior to the night shift, but changes of two to four hours in asleep and awake times were found at several points in the schedule. Despite fairly continuous disruption of the sleep/wake cycle in this study, performance was mainly affected on the night shift. Sleep quality ratings also declined over the course of the 2-2-1 week, with the lowest ratings given for the afternoon sleep before the night shift. On the other hand, Saldivar et al. (1977) showed that the 2-2-1 resulted in fewer ratings of poor quality sleep, particularly with regard to the night shift, than the straight-five rotation. Finally, in one study of job attitudes of ATCSs (Smith, 1973), the 2-2-1 was clearly the preferred rotation schedule even among the most senior group of controllers.

The current study was initiated in response to a request by the Miami Air Route Traffic Control Center (ARTCC) Quality Through Partnership (QTP) team to investigate a reported problem of sleepiness on the night shift. In an effort to understand more about sleep patterns associated with counterclockwise, rapidly rotating schedules, two types of rotations were compared to a straight day schedule. The first of these was a 2-2-1 (afternoons, early mornings, night) schedule, which involved two quick-turn-arounds of 8 hours each and a night shift at the end of the week. The second schedule was a 2-1-2 (afternoons, mid-day, early mornings), which involved two quick-turn-arounds of 12 hours each and did not include a night shift. The straight day schedule involved all early morning shifts, i.e., start times prior to 0800. These three schedules allowed for the comparison of 1) two counterclockwise rapidly rotating schedules and a straight early morning schedule, 2) rotations with and without a night shift, and 3) 8-hour and 12-hour quick-turn-arounds.

Because of the restrictions of the experimental protocol in the laboratory-based study of the 2-2-1 and a young ATC work force, Della Rocco and Cruz (1995) speculated that the disruptions observed in the laboratory might be exacerbated in data from the actual ATC work force. The 2-2-1 and 2-1-2, then, were hypothesized to result in phase shifts of asleep and awake times corresponding to the quick-turn-arounds in each schedule. They were also hypothesized to result in less sleep over the course of the week than the straight day schedule. In addition, the 2-1-2 was expected to be less disruptive to the sleep/wake cycle than the 2-2-1 because 1) the 2-1-2 did not contain a night shift and 2) the quick-turn-arounds were four hours longer than in the 2-2-1 schedule.

METHOD

Participants

Ninety-five volunteers from the Miami ARTCC completed daily log books over a period of two weeks. Twenty-four were selected for these analyses based upon the following criteria: 1) a full 5-day work week of data was reported and 2) the schedule for that work week corresponded to either a 2-2-1 (n=8), a 2-1-2 (n=8), or a straight day schedule (n=8). More participants were not included because of a holiday that occurred during the data collection period that resulted in schedules not meeting one or both of the criteria. Of the 24 selected participants, 18 (75%) were male and six (25%) were female; 20 were Caucasian, three were Hispanic, and one was Asian/Pacific Islander. The average age of these participants was 32.9 years (sd=7.9).

Twenty-three of the 24 participants were Air Traffic Control Specialists, and one participant was from the Airway Facilities work force. Of the 23 ATCSs, 14 (60.9%) were Full Performance Level (FPL), eight (34.8%) were Developmentals (in training), and one (4.3%) was an Area Supervisor. The average number

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of years spent working for the FAA was 7.1 years. Participation in the study was voluntary, and informed consent was obtained from each participant. Participants did not receive compensation for their participation.

Schedules

The schedules investigated in this study included straight days and two counterclockwise, rapidly rotating schedules, the 2-2-1 and the 2-1-2. The 2-2-1 schedule involved working two afternoon (A) shifts, followed by two early morning (E) shifts, followed by a night (N) shift. The 2-1-2 schedule involved working two A shifts, followed by a single mid-day (M) shift, followed by two E shifts. For purposes of this report, E shifts generally began between 0600 and 0800, M shifts began between 0800 and 1300, A shifts began between 1300 and 1600, and N shifts began after 2100. The 24 volunteers represented in this study reported work schedules that conformed, for the most part, to one of these schedule types. The straight day group generally worked all E shifts. Three volunteers, however, had exceptions within their schedules: Two worked one M shift during the week and another worked three M shifts during the week. All of the M shifts in this group were 9 and 10 a.m. start times. In addition, one volunteer in the 2-2-1 group worked an M shift (10 a.m. start time) on Day 2, rather than an A shift. Sixteen volunteers in this sample worked 8-hour days; the other eight worked 9-hour days (five days with two days off, followed by four days with three days off). Due to the small sample size, the 8- vs. 9-hour comparisons were not conducted. Table 1 provides the following information on each schedule: 1) shift type for each day of the week, 2) the approximate start time for each shift (computed by averaging all start times within each group and rounding to the nearest half hour), 3) the range of shift start times worked by the volunteers in each group, and 4) the approximate number of hours off between shifts.

Measures

Five subjective measures of sleep and sleepiness were analyzed: 1) Asleep Time, 2) Awake Time, 3) Total Sleep Time (TST), 4) Sleep Quality Ratings (SQR), and 5) Stanford Sleepiness Scale (SSS) ratings (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973). SSS ratings were given for the start of the work day and the drive home from work. Data were col-

Table 1

Work Schedules

	Day 1	Day 2	Day 3	Day 4	Day 5
Straight Day Schedule					
Shift Type	E	E	E	E	E
Approximate Start Time	0730	0700	0700	0630	0630
Range of Start Times	0630-1000	0630-0900	0630-1000	0630-0700	0630-0645
Approximate Hours Off Between Shifts	16 hrs.	16 hrs.	16 hrs.	16 hrs.	
2-2-1 Schedule					
Shift Type	A	A	E	E	N
Approximate Start Time	1430	1330	0700	0600	2230
Range of Start Times	1330-1600	1000-1600	0600-0800	0600-0620	2200-2400
Approximate Hours Off Between Shifts	16 hrs.	8 hrs.	16 hrs.	8 hrs.	
2-1-2 Schedule					
Shift Type	A	A	M	E	E
Approximate Start Time	1430	1330	1030	0700	0700
Range of Start Times	1330-1500	1250-1400	0955-1100	0630-0700	0600-0745
Approximate Hours Off Between Shifts	16 hrs.	12 hrs.	12 hrs.	16 hrs.	

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lected in a daily logbook modified from those developed by the National Aeronautics and Space Administration (NASA) (Gander, Myhre, Graeber, Andersen, & Lauber, 1989) for use in this study.

In the logbooks, volunteers were asked to distinguish between "in bed" and "asleep" times and between "awake" and "arise" times. TST was computed as the difference between reported Asleep and Awake Times. Long awakenings during the sleep period (30 minutes or longer) were subtracted from TST. SQRs comprised responses to the following scales: 1) "Falling asleep," from Not Difficult (1) to Difficult (5); 2) "My sleep was," from Not Deep (1) to Deep (5); 3) "Arising was," from Not Difficult (1) to Difficult (5); and 4) "I now feel," from Not Rested (1) to Rested (5). Responses were recoded so that high scores on each question indicated better sleep quality. Responses to all four questions were then summed, with a possible high SQR score of 20. Sleepiness was rated for the start of the workday and the drive home from work using the SSS, which instructed participants to select from seven statements ranging from, "Feeling active and vital; wide awake," (1) to, "Almost in reverie; sleep onset soon; losing struggle to remain awake," (7).

Procedure

The ARTCC facility management provided one hour of administrative time daily during the week of May 24, 1993, for data collection. Management and labor representatives jointly briefed employees that this study had been requested by the QTP team in response to ATCS complaints of sleepiness on the night shift. Two sets of data were collected: 1) logbooks and 2) a shift work questionnaire. The logbooks were completed daily over a two-week period. The questionnaire was completed on-site and data will be reported in a separate study. Logbooks and participant ID cards were number-coded to ensure anonymity, and, for this same reason, the on-site researchers did not approach the volunteers at the facility either to check or collect logbooks.

To improve the accuracy of the self-report data, volunteers were instructed to make entries in their logbooks at the time the event(s) occurred (i.e., to log meals at the time of the meal and to log sleep information upon waking from sleep). They were also instructed to have the on-site CAMI researchers check their logbooks on a regular basis. Problems with either the accuracy, legibility, or completeness of the entries were discussed with the volunteers. Personalized feedback regarding their own data was provided to participants upon request.

Design and Data Analysis

This study was a two-way mixed-model design with one between-groups factor and one repeated-measures factor for the following dependent variables: Asleep Time, Awake Time, TST, and SQR. The between-groups factor was Schedule Type. The within-subjects, repeated-measures factor was Day of the study. In the analysis of the SSS ratings, an additional repeated-measures factor, Rating (pre- and post-work), was included resulting in a three-way mixed-model design. The SPSSx version 4.1 for VAX/VMS MANOVA procedure for repeated measures was employed for the analyses in this study.

Multiple comparisons procedures (MCPs) were conducted utilizing the procedures for repeated measures described by Toothaker (1991) when significant interactions or main effects resulted from the MANOVA. Paired t-tests were used for the MCPs for both the within-subjects comparisons across Day (and Rating in the case of the SSS measure) and the within-subjects cell mean comparisons. Results of the t-tests for repeated-measure comparisons were compared to a Dunn's critical value with parameters $df=J(n-1)$ and $C=K(K-1)/2$, where J equaled the number of between-subject groups, n equaled the number of subjects per group, and K equaled the number of repeated measurements for computation of all pairwise comparisons. For fewer than all pairwise comparisons, C equaled the number of planned comparisons. Between-group MCPs involved a t statistic based on paired group means. The resulting statistic was compared to a Tukey critical value with parameters, $df=J(n-1)$ and number of means=J. Finally, for cell mean comparisons between groups, a t statistic to test means for Groups at Trials was computed using a pooled variance estimate, where $MSWCELL=(SS_{Between}+SS_{Within})/(J(n-1)+(k-1)J(n-1))$. The result-

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ing statistic was compared to a critical value of $h_\alpha / 2$, where h_α was the critical value for Tukey, based on the α level critical values with parameters, $df_{Between}=j(n-1)$ and $df_{Within}=(k-1)j(n-1)$, and number of means=j.

A 3 (Schedule) x 5 (Day) model was used for the analysis of Asleep Time, Awake Time, TST, and SQRs. Planned comparisons for Asleep Time and Awake Time were computed comparing each day to the next. This resulted in a total of four comparisons within each schedule type with seven degrees of freedom and a Dunn's critical value of 3.34. Multiple comparisons for TSTs and SQRs included: 1) a between-groups comparison of Schedule with 21 degrees of freedom and a Tukey critical value of 2.53; 2) a within-subjects comparison of the repeated measure with 21 degrees of freedom and a Dunn's critical value of 3.16 for all possible pairwise comparisons of Day; 3) cell mean comparisons between groups with a critical value of 2.45 computed as h; and 4) cell mean comparisons within subjects with seven degrees of freedom and a Dunn's critical value of 4.03 for all possible pairwise comparisons.

A 3 (Schedule) x 5 (Day) x 2 (Rating) MANOVA was computed for SSS ratings for the start of the workday and the drive home. Planned multiple comparisons for SSS ratings included: 1) a between-groups comparison of Schedule with 21 degrees of freedom and a Tukey critical value of 2.53; 2) a within-subjects comparison of the repeated measure with 21 degrees of freedom and a Dunn's critical value of 3.16 for all possible pairwise comparisons of Day; 3) cell mean comparisons between groups with a critical value of 2.45 computed as h; and 4) 25 planned cell mean comparisons within groups with seven degrees of freedom and a Dunn's critical value of 4.78.

RESULTS

The results of the analyses of the following dependent measures are presented: Total Sleep Time (TST), Asleep and Awake Times, Sleep Quality Ratings (SQR), and Stanford Sleepiness Scale (SSS) ratings. Each of the dependent measures were assessed in terms of potential sleep/wake cycle disruption of the

Table 2

Means and Standard Deviations for Total Sleep Time (in hours) by Day of the Week for the Straight Day, 2-2-1, and 2-1-2 Schedules.

	Day 1	Day 2	Day 3	Day 4	Day 5
Day Schedule	E	E	E	E	E
Mean	6.2	6.3	6.2	5.8	5.6
SD	1.3	1.3	1.0	1.0	1.1
2-2-1 Schedule	A	A	E	E	N
Mean	8.3	7.7	5.1	5.1	2.4*
SD	1.0	1.1	0.7	0.8	0.8
2-1-2 Schedule	A	A	M	E	E
Mean	8.2	7.3	7.6	6.0	5.9
SD	1.7	1.5	0.7	0.8	0.7

* The TST listed for Day 5 represents sleep taken on Day 4 in the afternoon prior to the night shift.

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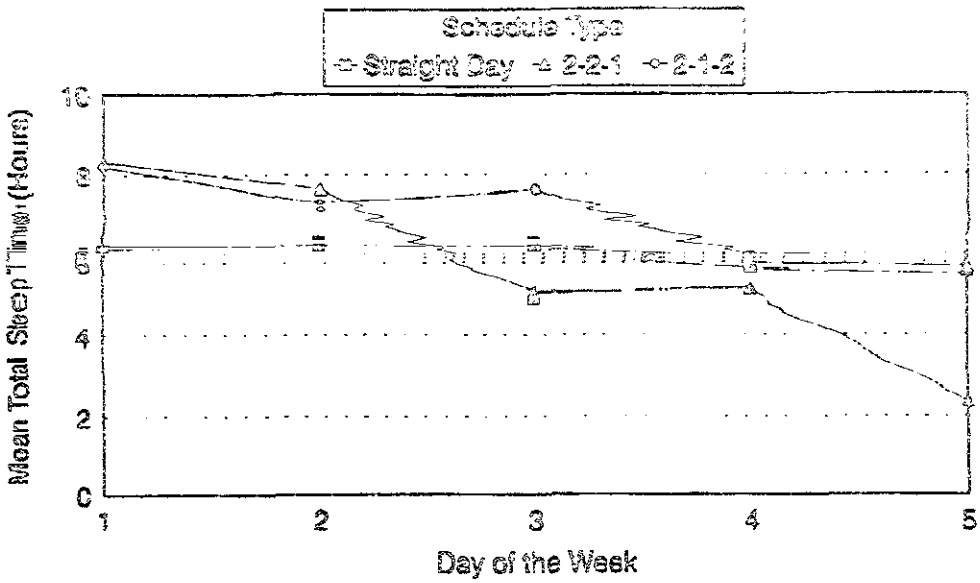

Figure 1. Mean Total Sleep Time by Day of the Week for the Straight Day, 2-2-1, and 2-1-2 Schedules.

2-2-1 and 2-1-2 schedules, as compared to the straight day schedule.

Total Sleep Time

To test the hypothesis that working the 2-2-1 and 2-1-2 schedules would result in sleep loss, as compared to the straight day schedule, TST was computed for the sleep periods prior to each day of the work week. Table 2 presents the means and standard deviations of TST for each group by day of the week.

Figure 1 presents data for the mean TST by day of the week for each shift schedule. Data revealed 1) a consistent average TST for the straight day schedule across the work week, 2) equal or greater TST for the 2-1-2 on each day of the work week, and 3) two relatively large decreases in TST for the 2-2-1 corresponding to each quick-turn-around. A 3 (Schedule) x 5 (Day) between groups, repeated measures MANOVA was computed for TST. The results of the MANOVA for TST are presented in Table 3.

The MANOVA for TST revealed a significant Schedule by Day interaction, $F(8,84)=11.64$, $p<.01$ and significant main effects for Schedule, $F(2,21)=8.22$, $p<.05$ and Day, $F(4,84)=35.64$, $p<.01$. Multiple comparisons of TST revealed the following:

1. Comparisons of Schedule by Day Interaction (Between Groups)

a) The first two days of the schedule showed no difference in TST between the 2-2-1 and the 2-1-2 schedules. On Day 1, TST for both the 2-2-1 (M=8.3 hours) and 2-1-2 (M=8.2 hours) schedules (afternoon shifts for both) was greater than for Day 1 of the straight day schedule (M=6.2 hours), $t=3.86$, $p<.05$ and $t=3.63$, $p<.05$, respectively.

b) TST for Day 2 of the 2-2-1 (M=7.7 hours), but not the 2-1-2, was significantly longer than for Day 2 of the straight day schedule (M=6.3 hours), $t=2.53$, $p<.05$.

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Table 3

MANOVA Summary Table for Total Sleep Time

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Schedule	2	36.07	18.03	8.22*
Between Subjects	21	46.05	2.19	
Day	4	131.28	32.82	35.64**
Schedule by Day	8	85.72	10.72	11.64**
Within Subjects	84	77.35	0.92	

*p<.05
**p<.01

c) Day 3 was the first quick-turn-around for both the 2-2-1 and 2-1-2. TST for Day 3 of the 2-1-2 (M=7.6 hours) was significantly longer than for the 2-2-1 (M=5.1 hours), t=4.78, p<.05 and the straight day (M=6.2 hours), t=2.58, p<.05. There was no difference in TST for Day 3 between the 2-2-1 and the straight day schedules.

d) The fourth day for all of the schedules was an early morning shift and was the second quick-turn-around for the 2-1-2. There was, however, no difference in TST on any of the comparisons among schedules.

e) Finally, TST on Day 5, was significantly lower for the 2-2-1 schedule (M=2.4 hours) than for the straight day (M=5.6 hours), t=6.01, p<.05, or the 2-1-2 schedule (M=5.9 hours), t=6.46, p<.05. There was no difference in TST for Day 5 between the 2-1-2 and straight day schedules.

2. Comparisons of Schedule Effect (Between Groups)

Although mean TST over the course of the work week was lowest for the 2-2-1 schedule (M=5.7 hours), it was not significantly lower than the mean TST for the straight day schedule (M=6.0 hours). The 2-1-2 schedule obtained the greatest mean TST over the work week (M=7.0 hours), and this was significantly higher than both the 2-2-1, t(21)=3.93, p<.05, and the straight day schedule, t(21)=2.90, p<.05.

3. Comparisons of Day Effect (Within Subjects)

a) Within the straight day schedule, no significant differences were revealed from one day to the next.

b) Within the 2-2-1 schedule, TSTs for Day 1 (M=8.3 hours), Day 2 (M=7.7 hours), Day 3 (M=5.1 hours), and Day 4 (M=5.1 hours) were significantly higher than for Day 5 (M=2.4 hours), t(7)=21.08, p<.05; t(7)=9.98, p<.05; t(7)=6.00, p<.05; and t(7)=9.37, p<.05, respectively. In addition, TST within the 2-2-1 for the two afternoons, Days 1 and 2, was significantly higher than for the two early mornings, Day 3, t(7)=5.86, p<.05 and, t(7)=4.44, p<.05, respectively, and Day 4, t(7)=6.44, p<.05 and t(7)=4.13, p<.05, respectively.

c) Finally, within the 2-1-2 schedule, TST for Day 3 was significantly higher than for Day 4, t(7)=6.38, p<.05, or Day 5, t(7)=7.67, p<.05.

Asleep and Awake Times

To test the hypothesis that the 2-2-1 and 2-1-2 schedules would result in phase shifts in the sleep/wake cycle, the average Asleep and Awake Times were computed, and the changes over the schedule were examined. Again, only the sleep periods prior to each workday were included in the analyses. Tables 4 and 5 present the means and standard deviations for Asleep and Awake Times, respectively, for each group by day of the week.

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Table 4

Means and Standard Deviations for Asleep Times by Day of the Week for the Straight Day, 2-2-1, and 2-1-2 Schedules.

	Day 1	Day 2	Day 3	Day 4	Day 5
Day Schedule	E	E	E	E	E
Mean	2320	2245	2250	2243	2309
SD	1.4	0.8	0.6	0.6	0.8
2-2-1 Schedule		A	A	E	E N
Mean	2415	2433	2422	2348	1621
SD	0.9	0.7	1.0	0.8	1.3
2-1-2 Schedule	A	A	M	E	E
Mean	2415	2435	2405	2340	2330
SD	1.3	1.0	0.3	0.8	0.7

Table 5

Means and Standard Deviations for Awake Times by Day of the Week for the Straight Day, 2-2-1, and 2-1-2 Schedules.

	Day 1	Day 2	Day 3	Day 4	Day 5
Day Schedule	E	E	E	E	E
Mean	0534	0510	0504	0434	0447
SD	1.0	1.3	0.9	0.7	0.4
2-2-1 Schedule	A	A	E	E	N
Mean	0850	0817	0540	0457	1843
SD	1.6	1.3	1.0	0.5	1.1
2-1-2 Schedule	A	A	M	E	E
Mean	0828	0754	0744	0540	0524
SD	1.6	1.4	0.7	0.5	0.5

A 3 (Schedule) x 5 (Day) between groups, repeated measures MANOVA was computed for Asleep Time. Results of the MANOVA revealed a significant Schedule by Day interaction, $F(8,84)=45.91$, $p<.01$ and significant main effects for Schedule, $F(2,21)=14.5$, $p<.01$ and Day, $F(4,84)=53.95$, $p<.01$. Planned multiple comparisons (to assess potential phase shifts in Asleep Time by comparing each day to the next within each schedule) revealed the following:

1) Within the straight day schedule, no significant differences in Asleep Time were found from one day to the next.
2) Within the 2-2-1 schedule, only the quick-turn around from the early morning to the night shift revealed a significant difference of 7.45 hours between the Asleep Times for Day 4 (M=2348) and Day 5 (M=1621), $t(7)=12.13$, $p<.05$.
3) Within the 2-1-2 schedule, no significant differences in Asleep Time from one day to the next were found.

A 3 (Schedule) x 5 (Day) between groups, repeated measures MANOVA was computed for Awake Time. Results of the MANOVA revealed a significant Sched-

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ule by Day interaction, $F(8,84)=100.99$, $p<.01$ and significant main effects for Schedule, $F(2,21)=103.66$, $p<.01$ and Day, $F(4,84)=74.75$, $p<.01$. Planned multiple comparisons to assess potential phase shifts in Awake Time by comparing each day to the next within each schedule revealed the following:

1) Within the straight day schedule, no significant differences in Awake Time were found from one day to the next.
2) Within the 2-2-1 schedule, advances in Awake Time corresponded to both quick-turn-arounds. Awake Time on Day 3 (M=0540) was approximately 2.5 hours earlier than on Day 2 (M=0817), $t(7)=4.23$, $p<.05$, and Awake Time on Day 5 (M=1843) was approximately 10.25 hours earlier than on Day 4 (M=0457), $t(7)=35.02$, $p<.05$.
3) Within the 2-1-2 schedule, Awake Time on Day 2 (M=0754) was approximately .5-hour earlier than on Day 1 (M=0828), $t(7)=3.60$, $p<.05$, and Awake Time on Day 4 (M=0540) was approximately two hours earlier than on Day 3 (M=0744), $t(7)=10.37$, $p<.05$. The transition from Day 1 to Day 2 was not a quick-turn-around, but the transition from Day 3 to Day 4 was the quick-turn-around from the mid-day to the early morning shift.

Sleep Quality Ratings

Subjective ratings of sleep quality were recorded for each sleep. Higher ratings indicated better sleep quality. Two subjects (both from the 2-2-1 group) did not rate their sleep prior to the night shift. A mean substitution, based on the ratings for this day by the other six volunteers in the 2-2-1 group, was used for these two missing ratings. Table 6 presents the means and standard deviations of SQRs for each group by day of the week. Figure 2 presents a line graph of the SQR averages.

Figure 2 presents data for combined SQRs by day of the week for all schedules. A 3 (Schedule) x 5 (Day) between groups, repeated measures MANOVA was computed for SQRs. The results of the MANOVA are presented in Table 7.

The MANOVA for SQRs revealed a significant main effect for Day, $F(4,84)=2.83$, $p<.05$. Planned multiple comparisons within-subjects revealed no significant differences between Days. Analyses of each of the SQR questions were conducted. The MANOVAs for each of the questions in the combined SQR resulted in Day main effects for ratings of how difficult it was to arise, $F(4,84)=3.29$, $p<.05$, and how rested the person felt, $F(4,84)=3.17$, $p<.05$. Neither of these ratings resulted in significant differences for comparisons between days, although the ratings tended to decline towards the end of the week.

Table 6

Means and Standard Deviations for Combined Sleep Quality Ratings by Day of the Week for the Straight Day, 2-2-1, and 2-1-2 Schedules.

	Day 1	Day 2	Day 3	Day 4	Day 5
Day Schedule	E	E	E	E	E
Mean	13.6	13.2	12.5	12.4	13.5
SD	3.2	3.2	2.8	2.4	3.4
2-2-1 Schedule	A	A	E	E	N
Mean	15.4	14.9	14.8	14.6	12.1
SD	3.2	3.5	3.2	3.7	2.0
2-1-2 Schedule	A	A	M	E	E
Mean	14.4	15.2	15.1	13.0	12.5
SD	3.0	3.4	1.8	2.1	2.2

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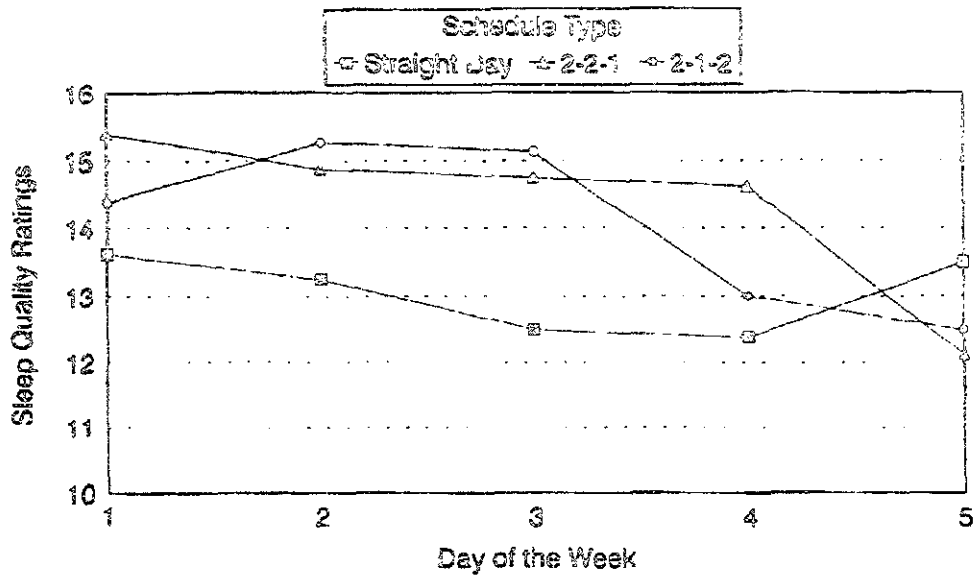

Figure 2. Combined Sleep Quality Ratings by day of the week for the straight day, 2-2-1, and 2-1-2 schedules.

Table 7

MANOVA Summary Table for Combined Sleep Quality Ratings

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Schedule	2	37.07	18.53	0.82
Between Subjects	21	476.5	22.69	
Day of Schedule	4	57.13	14.28	2.83*
Schedule by Day	8	55.27	6.91	1.37
Within Subjects	84	424.0	5.05	

*p<.05

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Table 8

Means and Standard Deviations for Stanford Sleepiness Scale Ratings at the Beginning of the Workday by Day of the Week for the Straight Day, 2-2-1, and 2-1-2 Schedules.

	Day 1	Day 2	Day 3	Day 4	Day 5
Day Schedule	E	E	E	E	E
Mean	2.4	2.8	2.8	2.5	3.1
SD	1.4	1.7	1.7	1.1	1.0
2-2-1 Schedule	A	A	E	E	N
Mean	2.0	2.1	2.2	2.6	2.8
SD	1.3	1.1	1.4	1.5	0.9
2-1-2 Schedule	A	A	M	E	E
Mean	1.5	1.8	1.8	2.9	2.5
SD	0.8	1.0	1.0	0.6	0.8

Table 9

Means and Standard Deviations for Stanford Sleepiness Scale Ratings of the Drive Home from Work by Day of the Week for the Straight Day, 2-2-1, and 2-1-2 Schedules.

	Day 1	Day 2	Day 3	Day 4	Day 5
Day Schedule	E	E	E	E	E
Mean	3.2	3.8	3.6	3.2	3.9
SD	1.3	1.4	1.4	1.0	1.2
2-2-1 Schedule	A	A	E	E	N
Mean	3.2	2.9	2.9	3.1	4.8
SD	1.5	1.2	1.6	1.5	1.5
2-1-2 Schedule	A	A	M	E	E
Mean	3.0	2.8	2.8	3.0	3.4
SD	1.1	0.9	0.5	0.8	1.4

Stanford Sleepiness Scale

Subjective ratings of sleepiness were recorded for the beginning of the work day and the drive home from work. Higher ratings indicated greater sleepiness. Tables 8 and 9 present the means and standard deviations of the SSS ratings for the beginning of the workday and for the drive home, respectively, for each group by day of the week.

Figure 3 reveals that sleepiness is consistently rated higher for the drive home from work than for the beginning of the workday for each group. In addition, the straight day group appears to be sleepier for the first three days of the week, both at the beginning of the workday and on the drive home, than the other two groups. A 3 (Schedule) x 5 (Day) x 2 (Rating) between groups, repeated measures MANOVA was computed for SSS ratings. The results of the MANOVA for SSS ratings are presented in Table 10.

The MANOVA for SSS ratings revealed significant main effects for Day, $F(4,84)=6.63$, $p<.01$ and Rating, $F(1,21)=22.08$, $p<.01$. The MANOVA revealed

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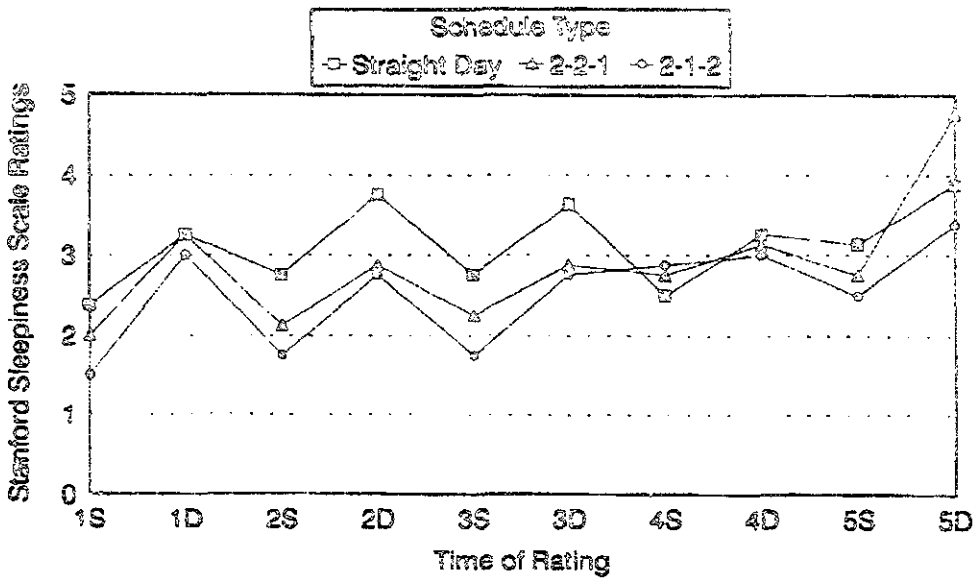

Figure 3. Stanford Sleepiness Scale Ratings for both the start of the workday (S) and the drive home (D) by day of the week for the straight day, 2-2-1, and 2-1-2 schedules.

Table 10

MANOVA Summary Table for Stanford Sleepiness Scale Ratings

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Schedule	2	14.53	7.27	1.12
Between Subjects	21	136.45	6.50	
Day	4	21.69	5.42	6.63**
Schedule by Day	8	9.63	1.20	1.47
Within Subjects	84	68.68	0.82	
Rating	1	50.42	50.42	22.08**
Schedule by Rating	2	0.23	0.12	0.05
Within Subjects	21	47.95	2.28	
Day by Rating	4	5.13	1.28	1.75
Schedule by Day by Rating	8	5.60	0.70	0.95
Within Subjects	84	61.68	0.73	

**$p<.01$

no significant differences in SSS ratings due to Schedule. The simple main effect for Rating indicated that the start of the workday (M=2.4) was rated lower on average than the drive home (M=3.3). Multiple comparisons examining the main effect for Day indicated that Day 5 (M=3.4) was rated higher than Day 1 (M=2.6), $t(21)=3.89$, $p<.05$; Day 2 (M=2.7), $t(21)=3.98$, $p<.05$; and Day 3 (M=2.7), $t(21)=3.78$, $p<.05$.

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DISCUSSION

The purpose of this study was to investigate three different shift schedules in use at ATC facilities with respect to potential disruption of the sleep/wake cycle. A straight day schedule and two variations of counter-clockwise, rapidly rotating shift schedules, the 2-2-1 and the 2-1-2, were analyzed in terms of subjectively reported total sleep time (TST), Asleep and Awake Times, and ratings of sleep quality and sleepiness.

It was hypothesized that both the 2-2-1 and 2-1-2 schedules would result in less TST over the course of the work week than the straight day schedule. Results of the analysis of TST, however, indicated that the 2-1-2 schedule resulted in greater TST over the course of the work week than either of the other two schedules. The 2-2-1 resulted in an average TST over the course of the week that was not significantly different from the straight day schedule. Thus, rapidly rotating schedules in this study resulted in as much, or more, TST for the week than the straight day schedule.

The straight day group obtained about 6 hours of sleep per night throughout the week (ranging from 5.6 to 6.3 hours). Saldivar et al. (1977) also reported that employees on the day week of the straight-5 schedule obtained 6 hours of sleep per night. These sleep durations are much lower than the 7.5 to 8.5 hours of sleep per night that Anch et al. (1988) reported for day workers.

The amount of sleep obtained by the 2-2-1 group showed a characteristic decline from approximately 8 hours before the two afternoon shifts to 5 hours before the two early morning shifts to 2.4 hours before the night shift. Studies by Saldivar et al. (1977), Schroeder et al. (1995), and Della Rocco and Cruz (1995) have all reported similar patterns for the sleep obtained on the 2-2-1 schedule, with declines in sleep duration associated with each quick-turn-around and with most people choosing to sleep in the afternoon prior to the night shift. In this study, however, the 2.4 hours of sleep before the night shift is notably lower than the 3.5 to 3.75 hours reported in previous studies.

The amount of sleep obtained per night by the 2-1-2 group generally declined across the work week from approximately 7.5 to 8 hours before the first three days of the schedule (two afternoons and a mid-day) to 6 hours before the two early morning shifts. This schedule had not been investigated in previous research, but the pattern exhibited in this study indicated that only the second quick-turn-around, from the mid-day to the early morning shift, resulted in a decline in sleep duration. Within all three schedules, the average amount of sleep obtained before an early morning shift was only about 6 hours, whether the early mornings were part of a straight schedule or a rapidly rotating one. Thus, the least amount of sleep was obtained before early morning shifts and before the night shift.

Disruptions in the timing of sleep may be as important to performance as sleep duration. It was hypothesized that disruptions in both Asleep and Awake Times would correspond to the quick-turn-arounds within the 2-1-2 and 2-2-1 schedules, but that the disruption would be greater for the 2-2-1 (8-hour quick-turn-arounds) because of shorter turn-around time than for the 2-1-2 (12-hour quick-turn-arounds). This hypothesis was only partially supported. Asleep times were relatively stable for both schedules, and Awake Times were significantly shifted only once by 2.5 hours in the 2-2-1 (not including the shortened sleep obtained prior to the night shift) and by 2 hours in the 2-1-2 . Both of these alterations in Awake Time corresponded with a quick-turn-around to an early morning shift.

Subjective measures of sleep quality indicated no difference in ratings due to schedule type. The ratings appeared to decline toward the end of the week, indicating a pattern of poorer sleep. This finding was similar to previous studies (Della Rocco & Cruz, 1995; Saldivar et al., 1977).

Subjective measures of sleepiness indicated no difference in ratings due to schedule type. Volunteers on all schedules rated themselves as more sleepy at the end of the day than at the beginning of the day and more sleepy on the last day of the work week than the first three days of the work week. Examination of individual volunteer's ratings, however, revealed that more ratings of extreme sleepiness were given by volunteers on the 2-2-1 schedule for the drive home after the night shift than on any other day or any other schedule. Of the eight volunteers in the 2-2-1 group, three rated the drive home after the night shift at (6) "Sleepy; woozy; prefer to be lying down; fighting sleep," and three others at (5) "Foggy; slowed down;

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beginning to lose interest in remaining awake." No more than two people on any day of any other schedule rated their sleepiness on the drive home at 5 or greater. The 2-1-2 schedule had the fewest number of ratings of 5 or higher on the drive home, suggesting that fewer people experienced extreme sleepiness on this schedule. While statistical analysis of these data did not reveal significant differences between groups, the ratings of extreme sleepiness for the drive home after the night shift on the 2-2-1, along with comments in the logbooks referring to falling asleep while driving and falling asleep on breaks during the night shift, suggest that sleepiness is a problem in the 2-2-1 schedule.

The data from this study suggest that at least one of the counterclockwise, rapidly rotating schedules, the 2-1-2, may improve in some ways on a straight day schedule of early morning start times. Specifically, it resulted in no less sleep than the straight day schedule, only one phase shift in Awake Time, no poorer sleep quality than the straight day schedule, and fewer ratings of extreme sleepiness on the drive home than the straight day schedule. This schedule provided 12 hours off between shifts and did not include a night shift. It also compressed the work week, providing approximately 8 additional hours off between work weeks as compared to a straight day schedule. The benefits of this schedule may indicate that counterclockwise, rapid rotations, per se, should not be dismissed as less desirable than clockwise rotations. In fact, Wilkinson (1992), in his critical review of rapidly rotating schedules, allowed that rapid rotations could be used to cover the morning and afternoon shifts. Indeed, the results of this study may indicate that the problems associated with counterclockwise, rapid rotations have more to do with working the night shift and early morning work start times than with quick-turn-arounds.

The 2-2-1 schedule resulted in: 1) no less sleep over the course of the work week than the straight day schedule, 2) only one phase shift in Awake Time, and 3) no poorer sleep quality than the straight day schedule. Both quick-turn-arounds in this schedule involved only 8 hours off between shifts, but only the sleep before the night shift and the number of ratings of extreme sleepiness on the drive home from the night shift were worse than the straight day schedule. The lack of disruption during the first four days of this schedule supports arguments made by Melton and Bartanowicz (1986) that the 2-2-1 allows for working four of the five shifts within normal waking hours and, therefore, should result in minimal disruption of the sleep/wake cycle allowing people to remain day-adapted. These researchers further argued that the longer period of time off between work weeks would provide ample time for employees to recover from any sleep debt created by the quick-turn-arounds.

The findings in this study add empirical data to the largely theoretical body of literature regarding counterclockwise, rapidly rotating shift schedules. The implications of these findings should be tempered by a number of factors. First, the early morning start times for the straight day schedule resulted in a control group with a lower amount of sleep than expected for a straight day schedule. Folkard's (1989) suggestion that early start times for the morning shift could result in similar sleep debt to that seen for the night shift was supported here. Second, this study excluded people who traded shifts, took annual leave or sick leave, or otherwise altered their schedule in such a way that it did not conform to a full 2-2-1, 2-1-2, or straight day work week. In doing so, this study may have focused on participants with particularly stable sleep patterns and potentially excluded individuals who do not cope well with either rotating schedules or early morning shifts. Third, the sample size in this study was small. Further empirical study of counterclockwise, rapidly rotating shift schedules should be done before generalizing these findings to other populations or advocating their use.

This report represents the first of several to report data collected in this field study. Other data will be reported in a separate study, including data from a shift work questionnaire that focused on health, work schedules, sleep patterns, life style, and eating habits. Future research is needed to address the effects of counterclockwise, rapidly rotating schedules, along with early morning start times in both rotating and non-rotating schedules and effective counter-measures to help people cope with sleepiness and fatigue on the night shift and on the drive home from the night shift.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1995 - 668-067/50127

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