FLIGHT SAFETY FOUNDATION
Airport Operations

Vol. 23 No. 2 *For Everyone Concerned with the Safety of Flight* March–April 1997

Air Traffic Control Counterclockwise Rotating Shift Schedule Appears to Affect Performance Only on Night Shift

In a U.S. Federal Aviation Administration Civil Aeromedical Institute study, air traffic controllers working a simulated "2-2-1" shift schedule experienced disruption of the sleep/wake cycle. Nevertheless, no significant performance degradation was found until the night shift on the last day of the 2-2-1 shift schedule.

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Aviation Writer

After the air traffic control (ATC) facility where he worked switched to a "2-2-1" shift schedule, one controller complained that the schedule's rapid shift changes, from afternoons to mornings to a night shift, had caused him to "suffer from bouts of fatigue and insomnia." Asserting that the 2-2-1 shift schedule is "designed for resilient people who function normally on five or six hours of sleep," the controller told the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) that the schedule is disruptive for persons who are accustomed to stable sleep patterns. "I know it affects the quality of my performance, and I know I am only one of many," he wrote.

Such complaints were among the reasons that the U.S. Federal Aviation Administration (FAA) Civil Aeromedical Institute (CAMI) in Oklahoma City, Oklahoma, carried out an intensive study of the 2-2-1 shift schedule, which is used at many ATC facilities. It is a counterclockwise, rapidly rotating schedule that requires ATC specialists to work two afternoon shifts (1600 hours to midnight, then 1400 to 2200), followed by two morning shifts (0800 to 1600, then 0600 to 1400) and finally a night shift (midnight to 0800) within five days.

The research aimed to determine the effect of the schedule, if any, on performance and to develop "fatigue countermeasures" to help controllers who work on the 2-2-1 shift schedule.

The two reports that emerged from that study indicated that the 2-2-1 shift schedule "substantially disrupted the sleep/wake" cycle for test subjects and adversely affected performance during the latter part of the schedule's single night shift. Nevertheless, test results also indicated that the effect on performance was limited to the night shift and might, therefore, be reduced by effective countermeasures.

Those two reports were published separately under the general title, *Shift Work, Age and Performance: Investigation of the 2-2-1 Shift Schedule Used in Air Traffic Control Facilities*. The Part I report, subtitled *The Sleep/Wake Cycle*, focused on the effect of the 2-2-1 shift schedule on sleep patterns. The Part II report, subtitled *Laboratory Performance Measures*, explained the results of laboratory performance tests of subjects following the 2-2-1 shift schedule. Both reports were written by CAMI researchers Pamela S. Della Rocco and Crystal E. Cruz.

The researchers suggested that “direct interventions,” such as naps or exposure to bright lights during the latter part of the night shift, might improve the alertness of ATC specialists working the 2-2-1 shift schedule. The reports also suggested that it might be advisable for ATC facilities to provide “sleep-management education” for employees and to redesign the shift schedules “to minimize the number of quick turnarounds” by controllers.

The analysis of CAMI laboratory test results revealed that:

- The 2-2-1 shift schedule” significantly disrupted the sleep/wake cycle,” but that disruption appeared to affect performance only on the night shift;

- The last two-thirds of the night shift was the primary time of concern because “the only significant decrement in performance” occurred during that part of that shift;

- Other than the decline in night-shift performance, the 2-2-1 shift schedule did not appear to significantly affect performance levels;

- Except for the “substantial learning curve” as work progressed, test subjects “maintained relatively stable performance” over the study’s four-week protocol, which included day-shift schedules; and,

- In most cases, the age of the tested subjects did not affect performance as much as previous studies had predicted it would.

According to the authors, the research suggested that “the problems [that] a counterclockwise, rapidly rotating shift schedule poses for complex-task performance may be localized to the night shift and that such problems could be addressed directly through fatigue and sleepiness countermeasures.”

Some controllers prefer the 2-2-1 shift schedule because it requires them to work only one night shift and it compresses the work week, thus allowing for more free time; others complain that the schedule disrupts their sleep patterns, thereby causing fatigue and, some say, weaker work performance.

“The rapid, counterclockwise rotations require that employees arrive at work progressively earlier throughout the schedule, thereby compressing the work week,” the report said. “In this schedule, a 40-hour work week is completed within 88 hours, as opposed to the 112 hours required on a straight-day schedule, and it results in 80 hours off between work weeks, compared to 62 hours on straight days.”

Although a number of previous field studies of ATC specialists had investigated the effect of the 2-2-1 shift schedule, none of those studies had involved controlled, laboratory-based research, and none had focused on specific measures of performance.

The Della Rocco and Cruz study (Part II) addressed the issue of whether “the subjects working the 2-2-1 [shift schedule] were able to maintain a relatively stable day orientation or whether the phase-advancing properties of the schedule would be so disruptive as to manifest in subject performance.”

An earlier FAA report said that the 2-2-1 shift schedule might be less disruptive than schedules that require “straight-five” work weeks on each of the shifts (morning, afternoon, night) because the 2-2-1 shift schedule allows controllers to work four of five shifts during normal working hours.[1] In theory, employees could maintain relatively stable sleep/wake cycles for those four days, with only one night shift to disrupt their sleep rhythms. Because that night shift comes at the end of the 2-2-1 shift schedule, any fatigue caused by it would not affect employees on a following workday, supporters of the 2-2-1 shift schedule contended.

Some aspects of the 2-2-1 shift schedule “are in contrast to current research recommendations about shift designs.”

But the CAMI researchers said that some aspects of the 2-2-1 shift schedule “are in contrast to current research recommendations about shift designs.” Because of the rapidly rotating work schedule, “the quick turnarounds provide employees with as little as eight hours between shifts to get home from work, sleep and return to work. This arrangement has the potential to result in cumulative partial sleep loss during the week because of the two quick turnarounds, as well as the circadian [sleep/wake] rhythm disruption,” the report said. Also, the transition from the morning shift to the night shift requires employees to sleep during the afternoon, which is “likely to result in poor-quality sleep.”

Prior to the new reports, a series of CAMI field studies at ATC facilities had indicated that workers on the 2-2-1 shift schedule typically sleep about 30 minutes less per week than do “straight-five” shift workers. Also, [ATC specialists] working on the 2-2-1 shift schedule “reported more fatigue than those working nonrotating, steady schedules.”[2]

To assess the effect of the 2-2-1 shift schedule, the CAMI researchers conducted a laboratory-based study that was designed to reveal the extent to which the schedule “resulted, or failed to result, in sleep and circadian rhythm disruption, performance decrements and changes in the subjective measures of sleepiness and mood.” Because some previous studies had found age to be a factor in ATC performance, the CAMI researchers included age as a factor in the laboratory assessments.

Researchers tested the extent to which the 2-2-1 shift schedule disrupted sleep patterns and resulted in cumulative partial sleep loss; affected the performance of test subjects on complex cognitive tasks; tended to cause more problems for older controllers; and affected performance in a way that continued into the following day-shift week, thus requiring a "recovery period."

The CAMI laboratory tests used 20 male subjects in two age groups: 10 subjects between the ages of 30 and 35 (mean age: 32 years), and 10 between the ages of 50 and 55 (mean age: 52.4 years). The younger age range was selected to represent ATC specialists when they reach full performance level; the older age range was chosen because ATC specialists must stop controlling air traffic when they reach age 56.

Researchers decided to use only men in the tests to "minimize cyclic variations that might have interacted with or masked circadian variations in female test subjects." All of the subjects had completed high school, and most of them had either attended college or earned a college degree. Although none of the subjects were ATC specialists, one man in the older group had formerly been a U.S. Air Force air traffic controller.

The subjects were tested in a four-week protocol (Table 1). During the first week, they adapted to wearing physiological monitors 24 hours a day; the second week they worked a day shift (0800 to 1630); during the third week the subjects worked a slight variation of the standard 2-2-1 shift schedule; and the fourth week they again worked a day shift. (On the final day of the study, the "workday" was abbreviated to allow for collecting equipment and debriefing.) Researchers created a "synthetic work environment" in the laboratory by using the multiple task performance battery (MTPB).

To assess the effect of the shift schedule on the subjects' performances, sleep rhythms, sleep/wake cycles and "subjective experiences of mood and sleepiness," researchers collected a number of measurements, including performance on the MTPB; physiological measures such as heart rate and activity level; daily logs of sleep/wake times and sleep-quality ratings; and scores on mood and sleepiness scales.

Central to the assessment of performance was the MTPB, which involved six computerized tests of processing information, tracking and monitoring. Subjects performed tasks, singly or in combination, that measured basic psychological or behavioral functions relevant to control of complex systems in general, and ATC and pilot tasks in particular. There were three MTPB tasks sessions each day except the final day of the study. The MTPB tasks were as follows:

- Red and green light monitoring, which required test subjects to respond to red and green light signals by pushing buttons corresponding to the lights that changed. Performance was measured by "mean response latency" (the average time a subject took to respond) and by the percentage of correct responses;

- Meter monitoring, which challenged subjects to press buttons to indicate whether a meter needle (shown on the computer screen) deflected to the right or to the left. Performance was measured by mean response latency and by the percentage of correct responses;

- Mental arithmetic, which required subjects to solve addition and subtraction problems involving two-digit numbers. Performance was measured by mean response time and percentage of correct responses;

- Target identification, which challenged subjects to recognize patterns involving histograms (six bars of varying heights, displayed on the computer screen). When two

Table 1
Shift Schedule for CAMI Laboratory Tests

Days	Protocol	Hours Since Last Shift
1	Adaptation	N/A
2	to wearing	N/A
3	physiological	N/A
4	monitors	N/A
5		N/A
6		
7		
8	0800-1630	–
9	0800-1630	15.5
10	0800-1630	15.5
11	0800-1630	15.5
12	0800-1630	15.5
13		
14		
15	1600-0030	–
16	1400-2230	13.5
17	0800-1630	9.5
18	0600-1430	13.5
19	0000-0830	9.5
20		
21		
22	0800-1630	–
23	0800-1630	15.5
24	0800-1630	15.5
25	0800-1630	15.5
26	0800-1200	15.5

Source: U.S. Federal Aviation Administration, Civil Aeromedical Institute (CAMI) comparison patterns (rotated by 90 degrees, 180 degrees, 270 degrees or not rotated at all) were presented on the screen, the subjects had to decide if one, both or neither of the comparison patterns matched the initial “target.” Performance was measured by mean response latency for all problems and by the percentage of correct responses;

- Code lock, which was a self-paced task that required subjects to decode a five-letter sequence and to recall that letter sequence from memory after a 15-second delay. Performance was measured by mean response latency and percent correct for both the solution and recall parts of the task; and,

- Critical tracking, which was presented before and after each two-hour MTPB session, challenged subjects to use a custom controller to stabilize an arrow at the center of the monitor screen. The arrow became increasingly unstable, finally going out of bounds when the subject was no longer able to control it. Performance was measured by the median score, from five trials, of how long the subject could control the arrow.

The CAMI researchers analyzed the performance data on three levels to determine what changes were related to the shift work schedules.

First, researchers standardized MTPB composite scores for each task during each two-hour session. Those scores were combined into composites for “total” tasks (all tasks); “passive” tasks (green light monitoring, red light monitoring and probability meters); and “active” tasks (target identification, arithmetic, code locks and critical tracking). The higher the composite score, the better the performance.

Second, researchers compiled raw scores for each MTPB task. And third, they examined “15-minute intervals” for passive tasks to help examine the effects of workload. Their analysis of the results by category is as follows:

The MTPB total composite scores (Figure 1) “revealed no significant differences between days, sessions or age that resulted from the 2-2-1 shift schedule.” The analysis indicated that test subjects continued learning the tasks well into the 2-2-1 shift schedule work week.

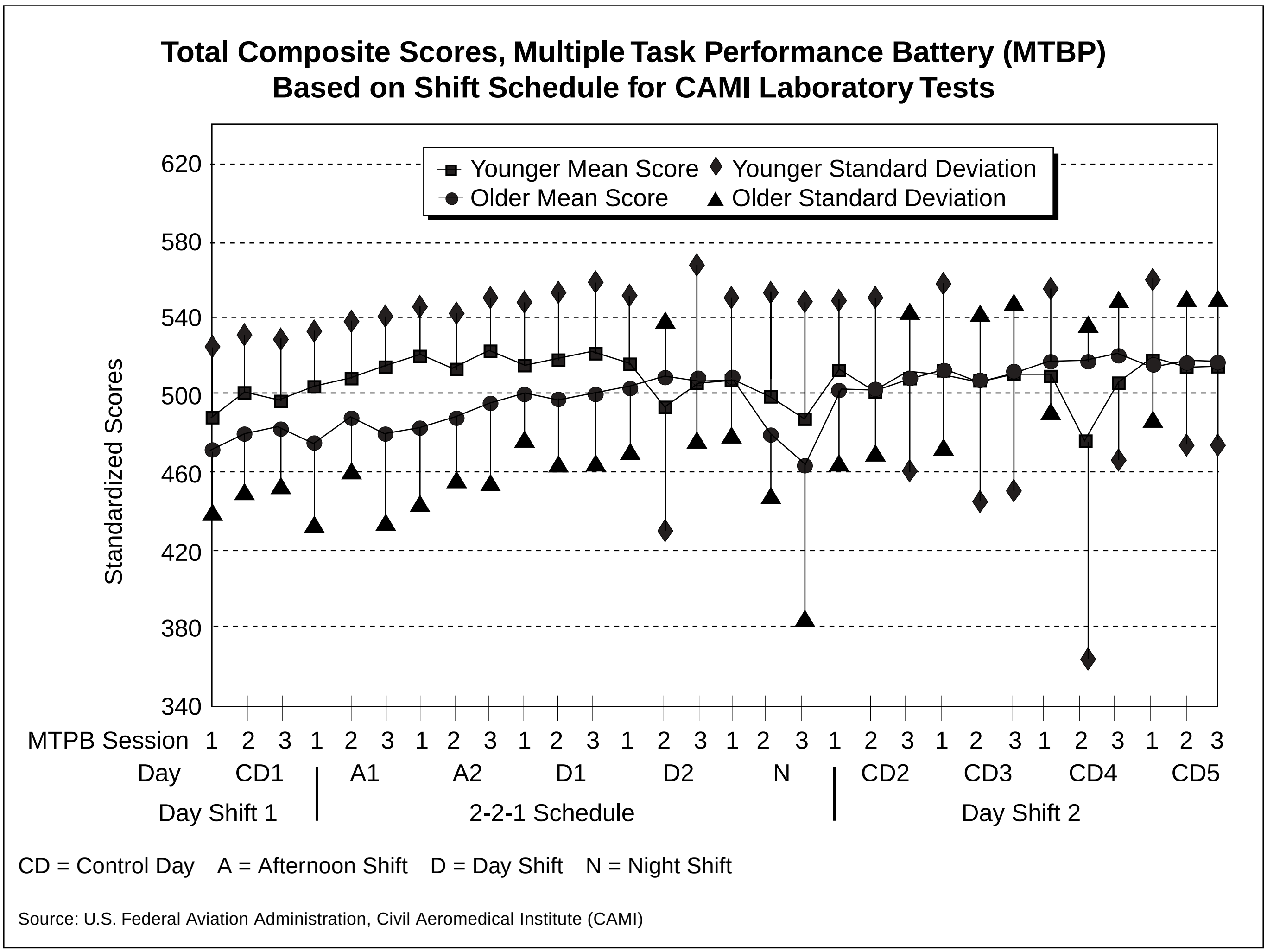

Figure 1

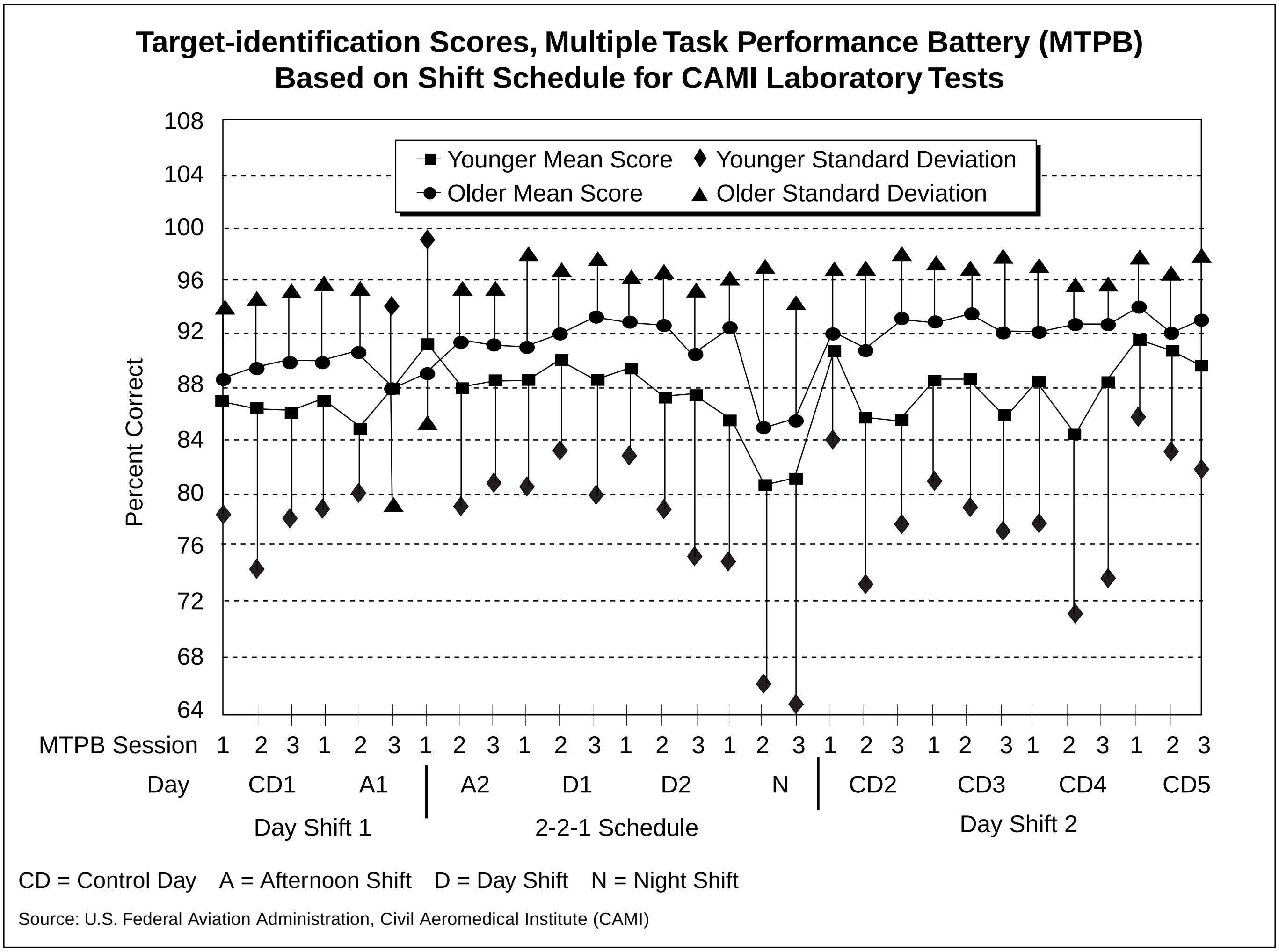

Figure 2

The passive-task composite scores indicated that "performance on the passive tasks declined significantly over the course of the night shift."

The active-task composite scores "revealed that performance on the night shift was significantly lower" than performance on active tasks during the previous day shift.

Data from MTPB individual tasks also indicated that the time required to solve code-lock tasks "was significantly slower on the night shift" than on the prior day shift.

Researchers found "a significant slowing" of the response time for the target-identification task during the third session of the night shift, compared with the third session of the previous day shift (Figure 2).

Test data did not show any significant differences in the subjects' accuracy in monitoring probability meters or their accuracy in monitoring the red and green lights. But the analysis did find "significant decrements [in] the response times" to the red lights as the workday progressed, with faster response times to the red lights during the first session of the workday than during the second or third session.

The CAMI research indicated that the night shift was the only time when the 2-2-1 shift schedule had a significant negative influence on the subjects' performance. "The detrimental effects of the schedule on performance were not evident in this study until the night shift, even though the sleep/wake-cycle data demonstrated significant disruption," the report said.

Specifically, the researchers said that the results indicated that most of the declines in performance levels occurred during the latter two-thirds of the night shift. For that reason, they suggested that "interventions to improve employee alertness may not be needed during the first few hours of the night shift but become critical during the final two-thirds of the shift."

The researchers said that the decrease in the speed and accuracy of test subjects performing the target-identification task during the night shift was "of particular note."

Among all the MTPB tasks, response time on the target-identification task decreased the most — about 23 percent — during the night shift. The report said that performance scores on other tasks were between zero percent and 12 percent lower during the night shift than they were during the other shifts.

"Significant decrements were found in both active- and passive-[task] composite scores during the third session of the night shift," the report said. "Thus, the hypothesis that both quick turnarounds within the 2-2-1 [shift schedule] would result in performance decrements was only partially supported."

Nevertheless, the CAMI researchers cautioned that because the composite scores combined measures of both speed and accuracy, "opposing changes in speed or accuracy due to the time of day or fatigue effects could have been masked or minimized by the analyses of the combined scores."

The detailed analysis of performance on each measure of the specific individual tasks showed weaker performance during the night shifts only on active tasks: code lock and target identification. "[Although] arithmetic performance revealed no significant differences due to the shift, both code lock and target identification did," the report said.

No significant decline in accuracy or speed was observed on the night shift in an individual measure on the specific passive tasks, such as the red and green light monitoring and probability meter monitoring.

In analyzing the night-shift results, the CAMI researchers said that "it remains unclear whether the performance decrements were due primarily to the sleep loss just prior to the night shift, or whether the decrements might be due solely to the effects of circadian variation." But the researchers wrote that "it did not appear that an adverse additive interaction resulted from the combination of sleep loss and time of day."

On the age factor, researchers reported that the test of code-lock recall "was the only task to reveal a hint that age, as well as the first quick turnaround in the 2-2-1 [shift schedule], might result in performance decrements. The older group demonstrated decrements in accuracy of recall on both quick-turnaround days." But the younger group showed weaker recall only on the night shift.

"The present study failed to find as many age-related differences as were predicted from the literature review," the report said. Nevertheless, researchers cautioned that the age-related finding "should not be generalized to the broader work force," because the CAMI test results might have been affected by the restriction in the test subjects' age range.

Analysis of sleep-pattern data confirmed reports that the 2-2-1 shift schedule "substantially disrupted the sleep/wake cycle."

Although many test subjects complained that they felt "shift-lagged" on the first day of the final week of their schedule (the first working day after the 2-2-1 shift schedule night shift), their fatigue feelings "were not reflected in the performance."

The CAMI researchers concluded that "performance on the first two days of the final day-shift week following the 2-2-1 [shift schedule] indicated that performance did not require a period of recovery."

The researchers cautioned that their findings "may be conservative in estimating the disruptive effects of the 2-2-1 [shift] schedule" because the tests subjects worked only one 2-2-1 shift schedule; instructions to the subjects required them "to restrict their life-styles to unusually stable patterns"; and the subjects were matched on mental abilities, which might not occur in the general work force.

The CAMI analysis of sleep-pattern data confirmed reports that the 2-2-1 shift schedule "substantially disrupted the sleep/wake cycle."

The report said that the sleep disruptions "were mainly in the form of phase-shifting," with the 2-2-1 shift schedule resulting in one sleep-phase delay of two hours, followed by two sleep-phase advances of two and 2.5 hours each in asleep times ... ."

In addition, "a significant age difference" was found in sleep times, "indicating that the older group, on the average, fell asleep approximately one hour before the younger group over the course of the study."

But the data "only partly supported" the hypothesis that there would be significant losses in the mean sleep durations (MSDs) on the two quick turnarounds. The sleep duration on the rapid transition from the day shift to the night shift (between days 18 and 19, Table 1, page 2) was "significantly shortened," to 3.7 hours, the report said.

But the sleep duration for the first quick turnaround (from the afternoon to the morning shift), although shortened, was not reduced enough to be statistically significant.

"[Although] sleep debt accumulated over the five workdays, the subjects made up the deficit by sleeping during the day on Friday after the night shift," the report said. Because the only significantly shortened MSD in this study occurred prior to the night shift, the researchers concluded that the 2-2-1 shift schedule "could not be characterized as resulting in cumulative partial sleep loss."

Nevertheless, the CAMI researchers found that "sleep quality ratings generally deteriorated over the course of the 2-2-1 [shift schedule] week." Those ratings reflected the subjects' difficulties falling asleep, the depth of their sleep, their difficulties arising after sleep and how rested they felt. The subjects reported that their worst sleep occurred during the afternoon of their transition to the night shift.

"The most important finding from the present study was the demonstration of the influence of the 2-2-1 [shift schedule] on the subjects' sleep/wake cycles," the researchers reported. But they stated that "caution should be used in generalizing the results," because it was a laboratory study, and a previous field study had indicated that the 2-2-1 shift schedule was not as disruptive for ATC specialists who were accustomed to it as it was for those who were not accustomed to it.

The CAMI researchers concluded that their results could serve "as a basic foundation for development of a research program on countermeasures and coping strategies."

They added, however, that "for any resolution of the discussion of the influence of the 2-2-1 [shift schedule], the circadian, physiological and additional data must be analyzed."

As a result of the sleep/wake-cycle analysis, the CAMI researchers recommended that certain countermeasures be investigated to determine whether they would help employees who work the 2-2-1 shift schedule. Those countermeasures included:

- Developing "direct interventions," such as naps or exposure to bright lights, "to improve alertness on the night shift";

- Providing "sleep-management" education for employees, designed to complement the 2-2-1 shift schedule design; and,

- Redesigning the schedule "to minimize the number of quick turnarounds."

Calling sleep management "a critical concept for effective coping strategies with the 2-2-1 [shift] schedule," the Part I report suggested that "employees should be instructed about the importance of maintaining a stable sleep/wake schedule, even on days off from work. This includes standardizing arise times, as well as times for exposures to sunlight in the mornings to maintain the timing of the biological clock."

The report also suggested that "it might be possible to improve the quality of sleep during the afternoon on the quick transition between the day and night shifts." Two possible ways of improving that sleep quality are:

- Improving the sleep environment, including ensuring that the bedroom is quiet and dark; and,

- Going to bed earlier, "thereby providing a greater opportunity for the individual to fall asleep, as well as increasing the duration of the sleep period."

Noting that their study addressed only "the acute effects of working one week of the 2-2-1 [shift] schedule," the CAMI researchers concluded that future research "should address the effects of working a quick-turnaround schedule on a chronic basis, as well as identification of individual differences in response to adaptation to the quick-turnaround schedules."♦

Editorial note: This article was adapted from two related reports: *Shift Work, Age, and Performance: Investigation of the 2-2-1 Shift Schedule Used in Air Traffic Control Facilities, I. The Sleep/Wake Cycle* (May 1995), and *Shift Work, Age and Performance: Investigation of the 2-2-1 Shift Schedule Used in Air Traffic Control Facilities, II. Laboratory Performance Measures* (September 1996). Both reports were written by Pamela S. Della Rocco and Crystal E. Cruz of the U.S. Federal Aviation Administration Civil Aeromedical Institute in Oklahoma City, Oklahoma. The 27-page Part I report includes 14 tables and an extensive reference list. The 23-page Part II report includes a reference list and several tables, as well as two appendices giving extensive documentation of performance results.

References

1. Melton, C.; Bartanowicz, R. *Biological Rhythms and Rotating Shiftwork: Some Considerations for Air Traffic Controllers and Managers*. U.S. Federal Aviation Administration (FAA). Report no. DOT/FAA/AM-86-2. 1986.

2. Melton, C. *Physiological Responses to Unvarying (Steady) and 2-2-1 Shifts: Miami International Flight Service Station*. FAA. Report no. DOT/FAA/AM-85-2. 1985.

Further Reading from FSF Publications

"Principles and Guidelines for Duty and Rest Scheduling in Corporate and Business Aviation." *Flight Safety Digest* Volume 16 (February 1997).

Koenig, R.L. "Research Suggests That Some Rotating Work Shift Schedules Do Not Harm Air Traffic Controllers' Sleep Patterns." *Airport Operations* Volume 21 (May–June 1995).

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