MINIMIZING WORK SCHEDULE DISRUPTION WITH BRIGHT LIGHT

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ABSTRACT

Shift workers suffer from a constellation of symptoms that can severely compromise their ability to perform optimally on-shift. The largest single factor in this regard is sleep disturbance, and there is little question that the primary cause of such sleep disturbance is circadian disruption. Recently, a number studies have demonstrated that timed exposure to bright light can help facilitate adaptation to rotating shift work schedules, at least in younger subjects. The aim of the current study was to assess the effects of bright light interventions in middle-aged individuals undergoing a simulated shift work schedule. Results indicate that although light was effective in resetting the circadian clocks of these subjects, there was little effect on measures of on-duty alertness and performance, or on off-duty sleep. These findings suggest that middle-aged subjects may be less phase-tolerant than young subjects, and they raise questions concerning the utility of bright light interventions in shift work populations.

Key words: Shift work, bright light, phototherapy, sleep, sleepiness, alertness, performance, temperature, circadian rhythms, aging.

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INTRODUCTION

Rotating shift work is a reality of our 24-hour society. In virtually all areas of commerce, from health care to transportation to energy production, round-the-clock operations play a vital role. Yet, the full benefits of working around the clock are compromised by the conflict between work hours and the human circadian timing system. Indeed, this conflict can become a substantial liability. It has been demonstrated, for example, that workers on rotating shifts (particularly night shift) are significantly less productive than workers on normal day shift (Bjerner and Swenssen 1953; Folkard and Monk 1985; Mott, et al. 1965) and industrial accidents are significantly higher in shift work operations (Harris 1977; Wiener 1984). Moreover, shift workers make greater use of health care services than do permanent day workers. They have a higher incidence of psychosocial complaints (Rutenfranz, et al. 1978), a higher rate of gastrointestinal problems (Angersbach, et al. 1980), higher levels of prescribed drug use (Reinberg 1986), higher levels of stress (Kundi, et al. 1981), reduced immune function (Nakano, et al. 1982) and poorer sleep (Knauth, et al. 1980; Akerstedt 1988). As a result, they are generally less satisfied with the quality of their lives (Rutenfranz, et al. 1978).

The largest single factor contributing to shift worker problems is sleep disturbance. A vast majority of shift workers complain about their sleep, primarily with respect to the quality of day sleep following the nightshift (Rutenfranz, et al. 1978; Akerstedt 1985; Akerstedt 1987; Akerstedt 1988). There is little question that the primary cause of such sleep disturbance is circadian disruption. In healthy adults, sleep tends to occur at a particular phase in the course of body core temperature (Wever 1979; Zulley, et al. 1981). Under the entrained conditions of normal, daily life major nocturnal sleep is typically initiated about 5 to 6 hours prior to the temperature minimum (i.e., the majority of sleep occurs on the declining portion of the temperature curve).

Unless the circadian system has adequately readjusted, this relationship is altered in individuals trying to sleep during the daytime, such that sleep is attempted several hours after the temperature minimum. In other words, the shift worker is attempting to sleep on the rising portion of the temperature curve. Even if one is able to initiate sleep at this circadian phase, it is virtually impossible to maintain it (Akerstedt and Gillberg 1981; Akerstedt and Gillberg 1982). As such, day sleep is often light and fragmented (Knauth, et al. 1980; Akerstedt 1988). This also leads to a greater likelihood that sleep will be disrupted by the intrusion of environmental factors, such as noise, light, and higher ambient temperature. As a consequence of this displacement of sleep relative to the circadian cycle, the average sleep duration of nightshift workers is 2h to 4h shorter than that of age-matched individuals sleeping at night (Knauth, et al. 1980; Tepas and Carvalhais 1990). Chronic sleep loss at home is directly related to reduced alertness on the job. This, in turn, may have an indirect impact on performance efficiency.

In addition to the indirect effects of sleep loss on subsequent waking function, displacement of the circadian system can have a direct influence on performance. The circadian variation in numerous performance measures is well-documented (Mott, et al. 1965; Monk, et al. 1983; Folkard, et al. 1985; Folkard, et al. 1985; Folkard 1990; Monk 1990). With few exceptions, the variation in performance efficiency across the 24-hour day parallels the circadian course of body core temperature with poorest performance occurring around the temperature minimum. Thus, rotating workers on nightshift are required to perform at a time 180 degrees out of phase with the time of maximum performance.

During the past several years, a number of laboratory and field studies have demonstrated that timed exposure to bright light can help facilitate adaptation to rotating shift work schedules (Eastman 1986; Campbell and Dawson 1990; Czeisler, et al. 1990; Dawson and Campbell 1991; Eastman 1992). Improved daytime sleep, as well as enhanced nighttime alertness and performance, have been reported. In virtually all of these studies, the subject samples have consisted of healthy young adults, usually with a maximum age of about 30 years. Although such studies provide valuable data, they suffer from a lack of face validity, inasmuch as, a large proportion of rotating shift workers in the United States are over the age of 40. Moreover, perhaps because of the changes in sleep and circadian rhythms that become apparent at around age 40, it is this group of shift workers that is likely to suffer most from maladaptation to rotating shift work schedules. It is, therefore, important to assess the effects of bright light interventions in middle-aged individuals. Such an assessment was the focus of the current study.

METHOD

Subjects. Thirty subjects between the ages of 40 and 60 were enrolled in the study. The data sets of four of the subjects were incomplete, due to non-compliance with the research protocol (in the case of 2 subjects), or as a result of equipment malfunction (in the case of two subjects). Thus, this report is based on the data of twenty-six subjects (7 females, 19 males), with an average age of 49.1 years (SD = 6.4 yrs). All subjects were in good health as determined by medical history and physical exams conducted prior to entry into the study. None had engaged in shift work for at least one year prior to enrollment. Subjects were informed that the purpose of the study was to examine adaptation to night work. They were paid for their participation.

Procedure. An overview of the experimental design is shown in Figure 1. After being fully informed of the nature and extent of the study and after giving informed consent, each subject reported to the lab for two consecutive nights of electrographically recorded sleep (Adaptation and Baseline nights). On the days following the Adaptation and Baseline nights, subjects practiced the work task (the Simulated Assembly Line Task (SALT), see description below) that they would be required to perform during the simulated night shifts. Performance was measured across the two days and was considered satisfactory when subjects achieved an average performance of 85%, and the change in performance between subsequent trials was less than 5%.

At 2400h on Day 1 (see Figure1b), the first of three consecutive night shifts commenced. From 2400h until 0800h the following morning, subjects worked, individually, at a specially designed "work station" situated in a quiet, well-ventilated, temperature-controlled room. The Active Group (N = 13; 10 males, 3 females) received a 4-hour pulse of bright light (>4000 lux) at the beginning of the first night shift (2400h -0400h), followed by ambient room illumination (<100 lux) for the remainder of the first shift. On the two subsequent night shifts, the Active Group was exposed to illumination of approximately 1000 lux for the duration of each shift. The Control Group (N = 13; 9 males, 4 females) was exposed to normal ambient illumination (<100 lux) throughout all 3 night shifts.

On the morning following each night shift, and following a standard breakfast, subjects retired to private, sound-attenuated bedrooms (no later than 0900h) for their major sleep period. Time in bed was held constant at 8 hours; that is, subjects were permitted neither to sleep longer than 8 hours, nor to arise before 8 hours had elapsed). Between arising from their major (daytime) sleep and the start of the next work shift, subjects were permitted to engage in leisure activities (e.g., hobbies, study, TV, reading) while they remained in the laboratory At no time during the study were they permitted to nap. Closed-circuit TV throughout the laboratory insured compliance with experimental instructions.

Performance testing. The Simulated Assembly Line Task (SALT) is a computer-based, continuous vigilance task in which graphic depictions of circuit boards scroll across the computer monitor at a fixed rate and quantity. The subject is required to examine each board for possible defect, and then to repair (when possible), or discard, the defective boards. Each subject's level of performance was assessed by measures of accuracy (both errors of omission and commission), and speed, of response.

Subjects performed the SALT continuously throughout the work shifts (with programmed, 1-to-2 minute rest periods interspersed), with the exception of a 15-minute snack break at 0400h and the scheduled intervals throughout the night for objective assessment of sleepiness (see below).

Alertness testing. At two-hour intervals throughout the work shift (0100h, 0300h, 0500h and 0700h) subjects' levels of alertness were assessed using a modified version of the Maintenance of Wakefulness Test, the Repeated Test of Sustained Wakefulness (RTSW) (Hartse, et al. 1982). For each test, the subjects were required to lie quietly on a bed in a darkened room. They were instructed to relax with eyes closed, but to try to remain awake for the 20-minute test session. EEG was continuously monitored during the trial and if sleep was detected within the 20-minutes, the subject was immediately awakened and the trial was terminated. On Shift Night 1, the 0100h and 0300h trials were not carried out, since the protocol required subjects in the Active Group to remain in front of the lights until 0400h. Rather, subjects remained at the work station, but were not required to perform the SALT during those 20-minute intervals.

Physiological measurement. All sleep (Major sleep and MWT's) was electrographically recorded. Major sleep episodes were scored in 30-second epochs according to standard criteria (Rechtschaffen and Kales, 1968). Body core temperature was continuously recorded while subjects were in the laboratory, except when showering or defecating, using an indwelling rectal thermistor connected to a Mini-Logger™

ambulatory recording device (Mini-Mitter, Sun River, Oregon). Data were collected in one-minute epochs and stored on computer for subsequent analysis.

Prior to statistical analysis, raw temperature data were demasked in order to offset the effects on temperature of postural changes associated with going to bed, and of sleep onset itself. De-masking was accomplished by subtracting a constant (0.3 ^{o}C) from temperature measures recorded while subjects were in bed. The evoked sleep effect was modeled as a trapezoid falling from zero to -0.3 ^{o}C over the first 30 minutes of bed time, then rising to zero in the 15 minutes following wake-up.

Complex cosine fits (24-hour with 12-hour harmonic) were applied to successive, de-masked twenty-four hour temperature curves to obtain three measures describing basic characteristics of the temperature rhythm: **mesor,** the average temperature of the fitted curve; **amplitude,** measured from peak to trough of the fitted curve; and **nadir,** the minimum point of the fitted curve, used to assess changes in circadian phase.

RESULTS

Baseline Measures

Table 1 compares Active and Control group measures of temperature and sleep at Baseline. There were no differences in circadian phase, amplitude or mesor between the Active and Control groups at Baseline. The average temperature minimum (Tmin) for the Active group was 0436h (SD = .92h) and 0421h (SD = .92h) for the Control group. For the entire sample (N=26), the average Tmin at baseline was 0428h (SD = .91h). There were no significant gender differences in any temperature measure, though there was a trend for women to exhibit larger amplitude (1.06 vs .82; $p = .051$) and higher mesor (37.16 vs 36.95; $p = .08$) than men. Within this relatively restricted age range, age did not correlate with any measure of temperature.

Likewise, there were no significant differences between the two groups in measures of sleep quality or architecture at Baseline, with the exception that the Control group spent a greater proportion of the night in Stages 3/4 than did the Active group [$F(1,24) = 4.67$, $p < .05$)]. Both the Active and Control groups had relatively poor sleep, compared to that of healthy young adults, showing average sleep efficiencies in the mid-to-high 80% range. As with temperature measures, there were no effects of gender on sleep measures, nor was age correlated with any measure of sleep quality.

Effects of the Simulated Shift Work Regimen

Body Core Temperature. Figure 2 shows changes in the circadian phase of body core temperature (Tmin), relative to sleep, in response to the nine-hour shift of the sleep/wake schedule. By the third night shift/daysleep period the average Tmin for both groups was significantly delayed compared to their Baseline minima ($p < .05$). However, following the three nights of shift work, the net average change in Tmin of the Active group showed a significant phase-delay relative to the Control group. Between Baseline and Night3/Daysleep3, the Active group showed a mean delay of 6.89 hours (SD = 2.3h), whereas, the Control group exhibited a mean delay of 3.86 hours (SD = 3.1 min) [$F(1,24) = 7.67$, $p = .012$). Thus, by Night3/Daysleep3, average Tmin occurred at 1118h (SD = 1.97h) for the Active group and at 0812 (SD = 3.27h) for the Control group. There were no significant group differences in amplitude, or mesor, following the three-night shift work protocol.

Daytime Sleep. To examine possible effects of the differential net phase-shift in body core temperature on daytime sleep quality, repeated measures analysis of variance (ANOVA) assessed group changes in sleep quality between Baseline sleep and sleep obtained on the final day sleep period (i.e., following three nights of shift work). In addition, for each group, sleep quality during the final day sleep was compared with sleep obtained on the Baseline night. These results are summarized in Table 2.

There were no significant differences between the Active and Control groups in measures of sleep quality for Daysleep 3, with the exception that the Control group showed a significant increase in the percentage of Stage 1, and the Active group exhibited a significant increase in the proportion of Stages3/4. Both groups exhibiting substantial reductions in the ability to sleep relative to Baseline (42 min and 55 min less total sleep time for Active and Control groups, respectively). However only the Control group's decline in total sleep time, sleep efficiency and wake after sleep onset (WASO) achieved statistical significance (see Table 2). As would be expected for sleep episodes initiated in the morning, both groups showed significant reductions in average REM latency relative to Baseline sleep.

On-Shift Alertness. Figure 3 shows average latencies to sleep onset on the Repeated Test of Sustained Wakefulness (RTSW) for the Active and Control groups across the second (3a) and third (3b) nights of simulated shift work. (Results of the initial night of shift work are not shown, since the Active group did not undergo the 0100h and 0300h tests (see Procedure)).

Although the Active group exhibited a consistent tendency to maintain wakefulness for slightly longer durations, on all tests throughout the night shift, particularly on the last night of shift work, repeated measures ANOVA revealed no statistically significant differences in sleep latency profiles on either night.

On-Shift Performance. The temporal course of performance (both in terms of accuracy and speed of response) across each night shift is shown in Figure 4. Two-way repeated measures analysis of variance (ANOVA) tested for differences in performance on all three nights of shift work. The between subjects factor was condition (Active vs Control), and the within subjects factor was time of night (eight sessions across the 8-hour work shift). Analyses revealed no significant differences between the groups, on any of the three nights, in terms of the accuracy with which subjects responded. With regard to speed of response, only on the first night of shift work was there a significant group difference [$F(1,24) = 3.99$; $p = .015$]. On this night, subjects in the Active group exhibited a tendency to *shorten* their response times as the night progressed (without loss of accuracy, see Figure 1a), whereas, Control subjects exhibited the opposite trend.

DISCUSSION

Human phase response curves to light indicate that exposure to illumination of adequate intensities can reset the circadian clock in a predictable way, dependent upon the time and duration of exposure (Honma, et al. 1987; Honma and Honma 1988; Czeisler, et al. 1989; Minors, et al. 1991). In the current study, we employed this body of knowledge in an effort to rapidly adjust the circadian systems of middle-aged subjects in response to a nine-hour shift in the normal sleep/work schedule. Based on previous work by a number of laboratories using young subjects, it was hypothesized that middle-aged subjects receiving appropriately-timed bright light exposure would exhibit enhanced on-shift alertness and performance, and improved off-duty sleep quality, when compared with a group of age-matched control subjects, as a consequence of the light-induced shift in their circadian timing systems.

This was not the case, however. Although light exposure was effective in shifting the circadian rhythm of body temperature by an average of almost seven hours, there was no significant effect on daytime sleep quality or nighttime performance when compared with subjects exposed to room light only. Moreover, although following three days on the reversed sleep/work schedule, daytime sleep of the Active group was not statistically significantly poorer than sleep on the Baseline night, subjects receiving bright light, nevertheless, obtained almost three-quarters of an hour less sleep on Day 3 than they did at Baseline. For sleep that was of relatively poor quality at the outset (83% sleep efficiency), a further reduction in sleep time of this magnitude can only be detrimental.

These results clearly suggest that bright light treatment in middle-aged subjects may be less effective than equivalent interventions in younger subjects. In a previous study using a similar protocol, but with younger subjects (mean age = 21.2 years) (Dawson and Campbell 1991), bright light exposure resulted in significant improvements in both nighttime alertness and day time sleep quality; this, in response to a phase shift in the circadian course of body core temperature of 5.9 hours. Thus, it appears that while the circadian systems of middle-aged individuals can be manipulated as readily as those of young subjects, such manipulations are not reflected in robust behavioral changes.

How can this discrepancy in results, apparently as a function of age, best be explained? The concept of "phase tolerance" may be useful in this regard (Dawson and Campbell 1991; Campbell and Dawson 1992; Campbell, et al. 1993). Phase tolerance refers to the capacity of an individual's sleep system to accommodate to perturbations in the usual phase relationship between sleep and the circadian timing system. For the young subjects studied earlier, a circadian phase shift large enough to move the temperature minimum out of the work period and place it *anywhere* in the daytime sleep period was sufficient to permit sound sleep of normal duration. That is, as long as Tmin fell within a relatively wide "sleep window", subjects were able to obtain daytime sleep that was equivalent in quality to that typically obtained at night.

It may be hypothesized that this "sleep window", within which Tmin must fall in order to achieve optimal sleep quality, narrows with age. Thus, in the middle-aged subjects studied here, it was not enough to shift Tmin such that it occurred *anywhere* within the sleep period. Rather, optimal sleep in these subjects may require a phase relationship between daytime sleep and the shifted rhythm of body core temperature that more closely approximates that which is observed under normal entrained conditions. Simply, the sleep systems of middle-aged individuals may be less phase tolerant.

If this is, indeed, the case then it could be further hypothesized that an additional phase shift of two-to-three hours might be sufficient to achieve improvements in sleep, alertness and performance equivalent to those exhibited by younger subjects. Although the results of the current study must be viewed as generally negative, they do provide some support for this notion. With regard to both performance efficiency and on-shift alertness, subjects exposed to bright light were consistently more alert and performed better than did control subjects, albeit not significantly. In addition, by the final day sleep, the Active group showed marginally better sleep. On the other hand, within the Active group, there was no significant positive relationship between the degree of phase shift and changes in a) daytime sleep efficiency, b) the ability to perform, or c) the ability to maintain wakefulness across the night shift, as might be expected if further delays of the circadian system are hypothesized to be of additional benefit. Thus, the question remains as to whether a greater phase shift would result in better adaptation to reversed sleep/work schedules. In any event, it is essential that the issue of possible differential age effects of treatment be clarified if bright light interventions are to be of maximum benefit in the applied setting.

In conclusion, it should be pointed out that programmatic cuts imposed by NIOSH, both in terms of funding level and the duration of this project, prohibited us from carrying out originally-proposed, and approved, components of the study which would have provided valuable additional information concerning the efficacy, and mechanisms, of bright light treatment in shift work settings. With regard to laboratory studies, we were unable to run a group of younger subjects in this protocol that would have permitted more valid age comparisons. Additionally, we were unable to assess the putative, differential effectiveness of light exposure aimed at manipulation of the circadian timing system versus light exposure designed to take advantage of overall CNS activation.

As for pilot studies in the applied setting, our requests for minimal additional funding to support specific research projects were denied. Likewise, our proposal to utilize previously approved funds for this use were rejected. As a result of policy decisions such as these, rigorous scientific investigations of bright light interventions, in field settings, continue to lag. The immediate losers of such administrative fiat are the 20 million American workers who must continue to contend with the debilitating effects of rotating shift work. In the longterm, however, all of Society is like to lose, as a consequence of reduced productivity and increased health care costs associated with carrying on shift-work-business-as-usual.

NIOSH comments on the last two paragraphs of this report

After review of the 01-A1 application, Dr. Campbell was contacted by NIOSH to discuss the programmatic importance of this proposal. It was conveyed that he should think in terms of conducting a relatively short laboratory phase (1 - 2 years), followed by a field phase in which he would evaluate the bright-light technique in a work setting, such as a control room. In so doing, he would have to obtain cooperation from an industrial source and thereby show that there is, in fact, an interest in this approach for dealing with shift work. Further, he was to identify the industrial situations for which this technique could possibly be used, should it prove worthwhile. The 01-A2 application did not reflect this guidance, because the proposal still involved a four-year laboratory study. The study section recommended only three years of funding and reduced the budget in the first year. Based on the above programmatic guidance, an award was negotiated for a two-year laboratory project at the full budget levels recommended for the first two years by the study section (inflation limited to 4% for year 2). It was expected that a competing renewal application would follow, if results of the funded two-year study were promising. The PI indicated in a letter of March 23, 1992, that he was "delighted to receive notification that our grant application ... will be funded for two years." He further stated, "With regard to any revision of research goals based on the reduced time and amount of the grant, we anticipate no major changes in the laboratory-based studies, with exception of the necessary cuts in total number of subjects to be studied. We have recently related to your office our strong commitment to implementing this research in an applied setting. To the extent that we are able to pursue this goal within the reduced scope of the project, we certainly intend to do so." With respect to the experimental design, a statistical concern was raised about having four study groups with just nine subjects in each, so an alternative idea was suggested that involved focusing on older individuals (40-60 years of age), studying 16 subjects in the combined light condition and 16 subjects in a control condition. The PI replied to this suggestion in a April 6, 1992, letter by saying, "As I stated in a previous letter, it is this older group of workers who suffers most from shift work maladaptation and, therefore, it is this group that is likely to benefit most from the implementation of bright light interventions. As such, we are delighted to adopt your proposal. It is clear that if the approach is effective in the older subjects that it will be *at least* as effective in younger individuals, as well. Nevertheless, should time and resources permit, we will also make a strong effort to collect data on a small group of younger subjects."

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Table 1. Comparison of sleep and temperature variables between Active and Control groups at Baseline. Shown are mean values with standard deviations in parentheses.

	Active (N = 13)	Control (n = 13)	Total (n = 26)
Sleep Latency (min)	13.92 (9.8)	13.34 (17.4)	13.63 (13.8)
Total Sleep Time (min)	387.50 (69.3)	410.90 (48.2)	399.17 (59.7)
Sleep Efficiency (%)	83.10 (14.1)	88.07 (8.5)	85.57 (11.7)
Wake after sleep onset (min)	78.04 (64.6)	55.0 (37.9)	66.52 (53.2)
% Stage 0	16.88 (14.1)	11.97 (8.5)	14.43 (11.7)
1	7.35 (3.6)	6.41 (3.4)	6.88 (3.4)
2	48.61 (11.8)	46.55 (9.7)	47.58 (10.6)
3/4	10.24 (6.4) *	16.71 (8.7)	13.47 (8.2)
REM	16.78 (6.9)	18.21 (7.3)	17.49 (7.0)
REM Latency (min)	100.96 (87.8)	99.77 (76.3)	100.34 (80.3)
Temperature minimum	0436h (.92h)	0421h (.92h)	0428h (.91h)
amplitude (°C)	.81 (.26)	.97 (.29)	.89 (.28)
mesor (°C)	36.99 (.20)	37.03 (.34)	37.01 (.27)
r^2	.82 (.05)	.82 (.04)	.82 (.04)

* $p < .05$

Table 2. Comparison of sleep measures on the final Day Sleep between Active and Control groups. Shown are mean values with standard deviations in parentheses.

	Active (N = 13)	Control (n = 13)
Sleep Latency (min)	18.92 (11.1)	8.54 (5.2)
Total Sleep Time (min)	345.71 (83.4)	355.88 (70.1) [1]
Sleep Efficiency (%)	75.06 (17.5)	76.03 (14.0) [1]
Wake after sleep onset (min)	113.87 (78.8)	109.33 (59.3) [1]
% Stage 0	24.94 (17.5)	23.61 (13.2) [1]
1	5.99 (3.1) [2]	9.38 (4.8) [2]
2	35.54 (13.7) [1]	33.62 (9.7) [1]
3/4	16.17 (6.1) [1,2]	15.82 (7.0) [2]
REM	17.15 (8.2)	17.19 (7.9)
REM Latency (min)	41.96 (19.5) [1]	42.42 (18.3) [1]

[1] significant change from own Baseline, $p < .04$
[2] significant effect of condition, $p < .05$

Figure Legends

Figure 1. Schematic diagram of the experimental protocol. Figure 1a shows the overall design, Figure 1b illustrates the lighting regimen (for the Active group) and timing of alertness testing and snacks on the three nights of simulated shift work. Control subjects were exposed to light of <100 lux throughout the three shifts. Subjects remained in the laboratory throughout the study.

Figure 2. Changes in the circadian phase of body core temperature relative to sleep, in response to bright light exposure and the nine-hour shift of the sleep/wake schedule. Circles denote average fitted temperature minima of the Active group (closed circles) and the Control group (open circles). Standard errors are shown. Both groups exhibited significant shifts relative to Baseline (* $p < .05$), and the Active group showed a significantly greater net shift compared to Controls (** $p = .012$).

Figure 3. Average latencies to sleep onset on the Repeated Test of Sustained Wakefulness (RTSW) for the Active (solid line) and Control (dotted line) groups across the second (3a) and third (3b) nights of simulated shift work. Standard errors are shown. There were no significant differences between the groups on either night.

Figure 4. Temporal course of performance across each night shift for the Active (solid line) and Control (dotted line) groups. Panels a-c show average (and standard error) performance as measured by accuracy of response (% correct). Panels d-f show average response times across the night (with standard error). Only time to respond on Night Shift #1 (panel d) showed a significant time x condition interaction ($p < .02$).

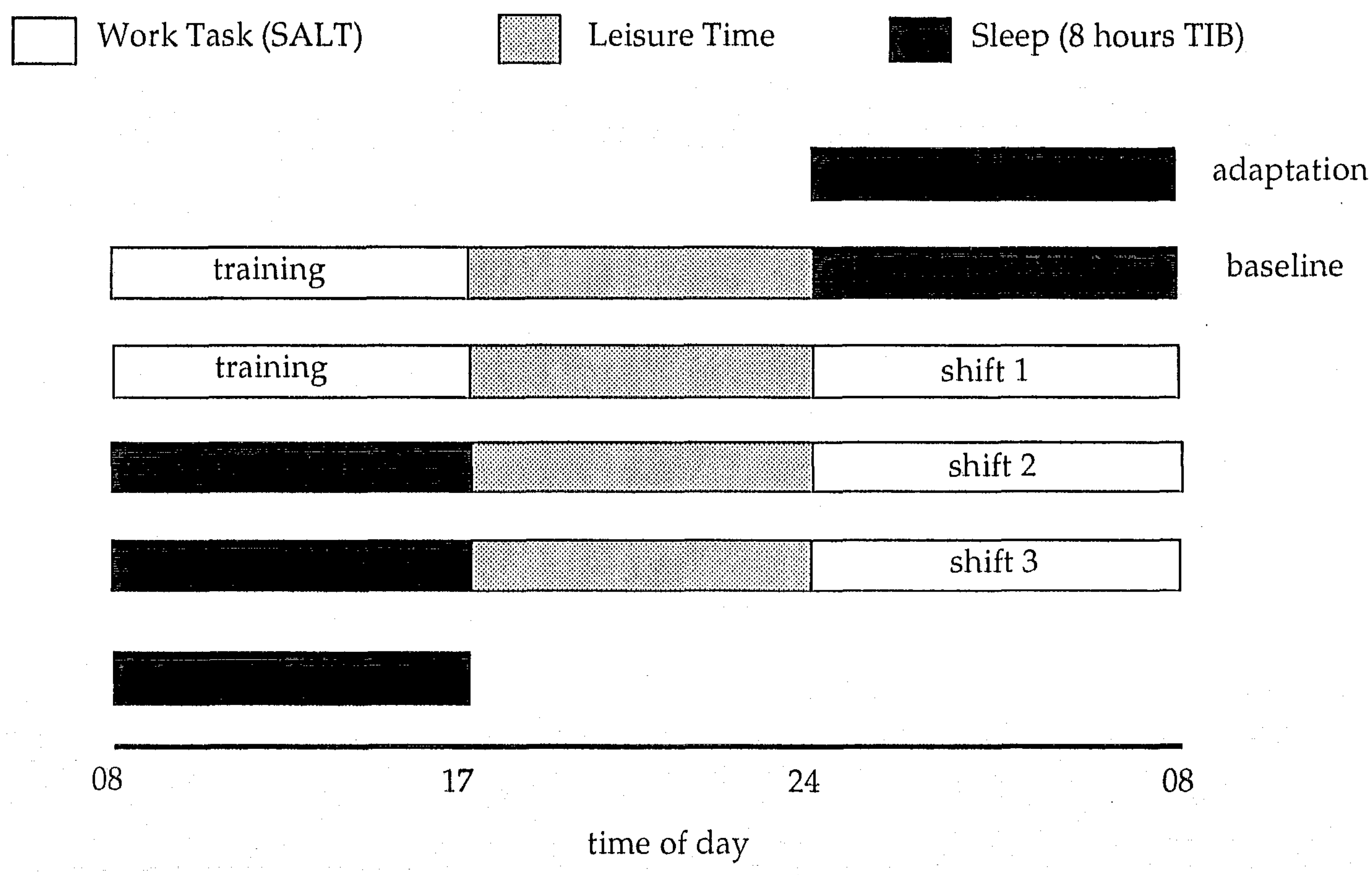
Work Task (SALT)
Leisure Time
Sleep (8 hours TIB)
adaptation
baseline
training
training
shift 1
shift 2
shift 3
08
17
24
08
time of day

Figure 1a

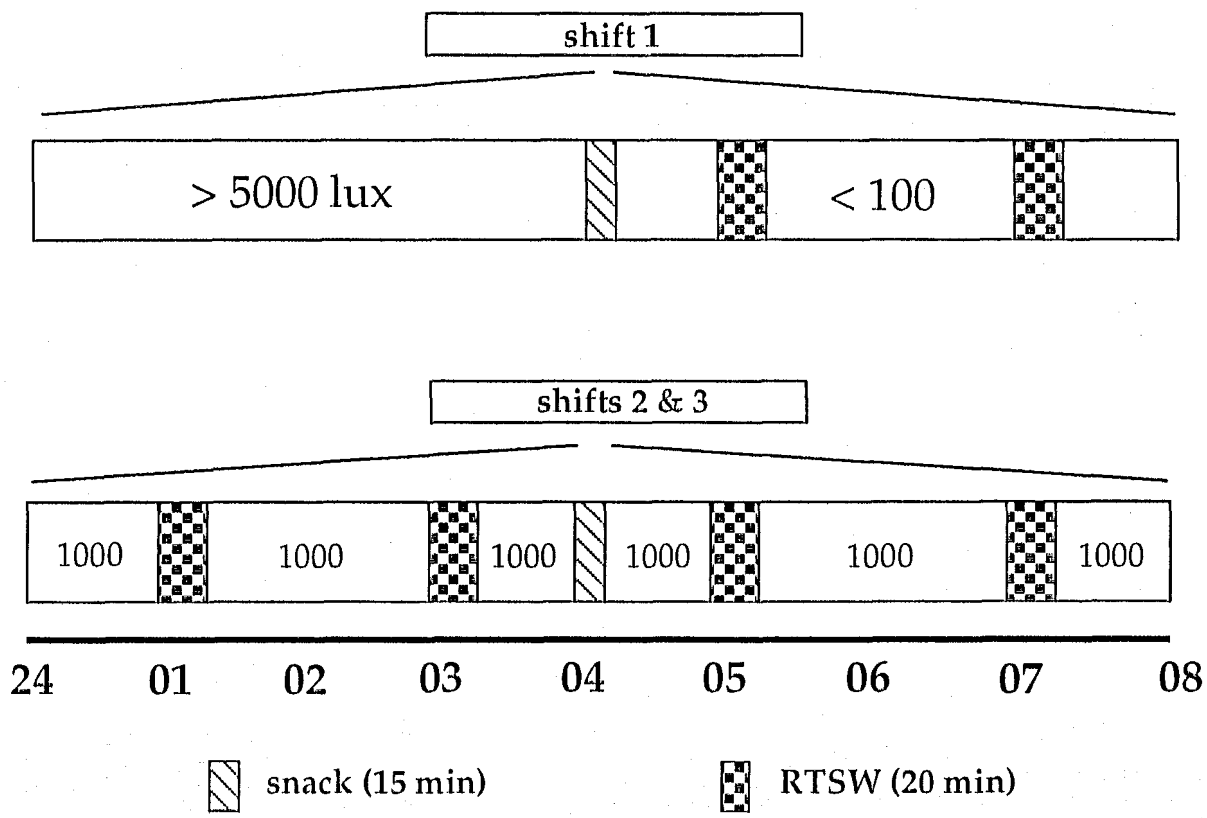
shift 1
> 5000 lux
< 100
shifts 2 & 3
1000
1000
1000
1000
1000
1000
24
01
02
03
04
05
06
07
08
snack (15 min)
RTSW (20 min)

Figure 1b

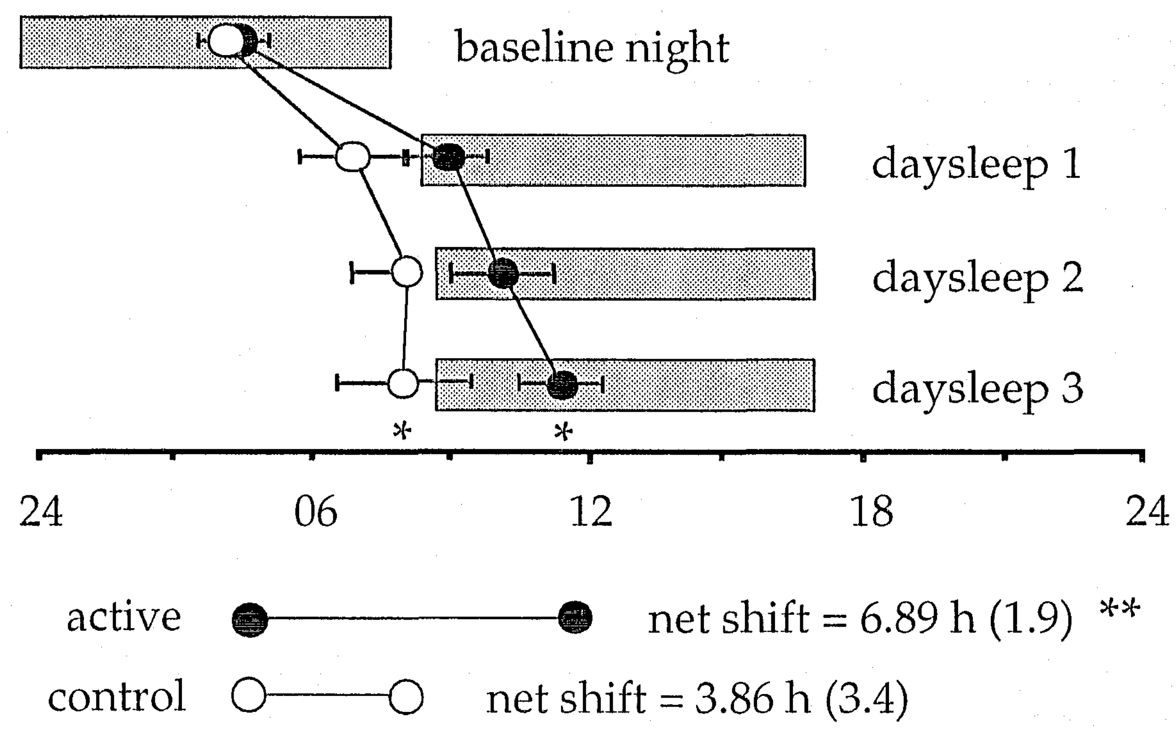
baseline night
daysleep 1
daysleep 2
daysleep 3
*
*
24
06
12
18
24
active
control
net shift = 6.89 h (1.9) **
net shift = 3.86 h (3.4)

Figure 2

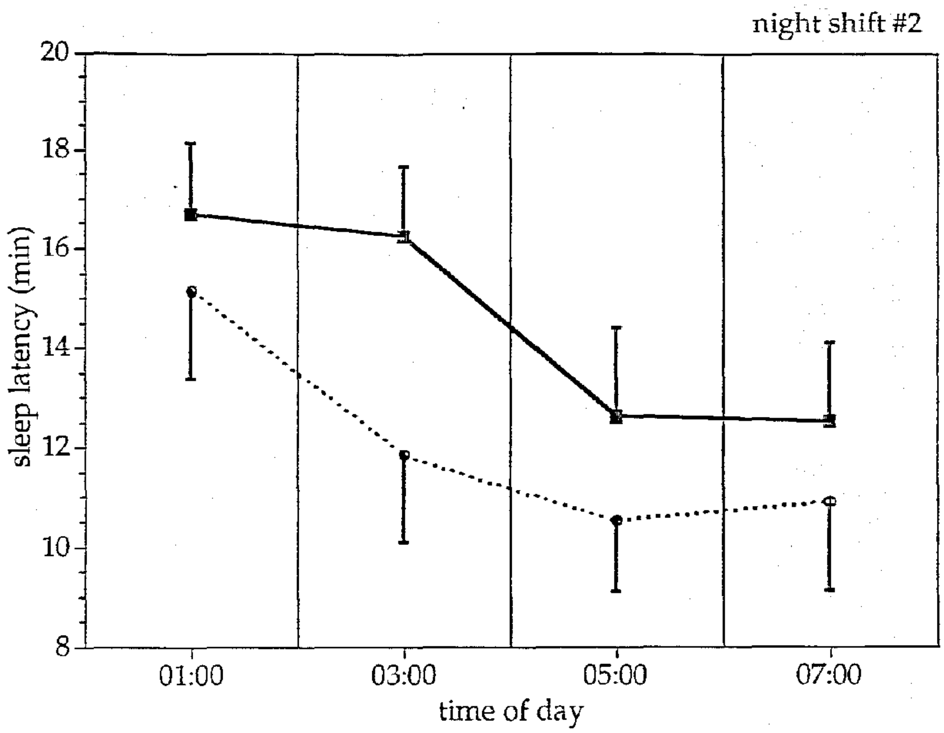

Figure 3a

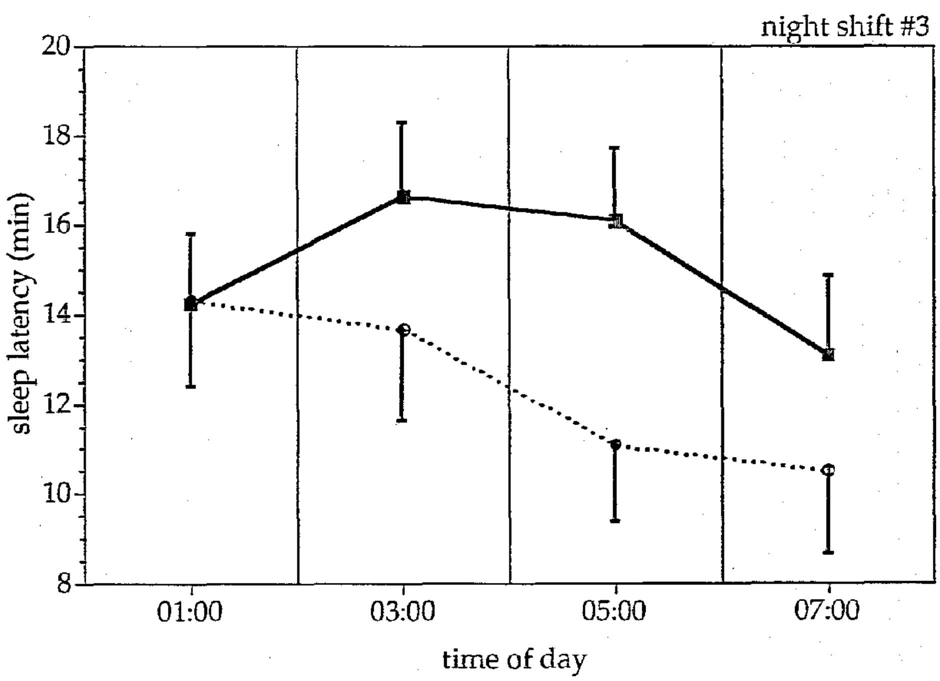

Figure 3b

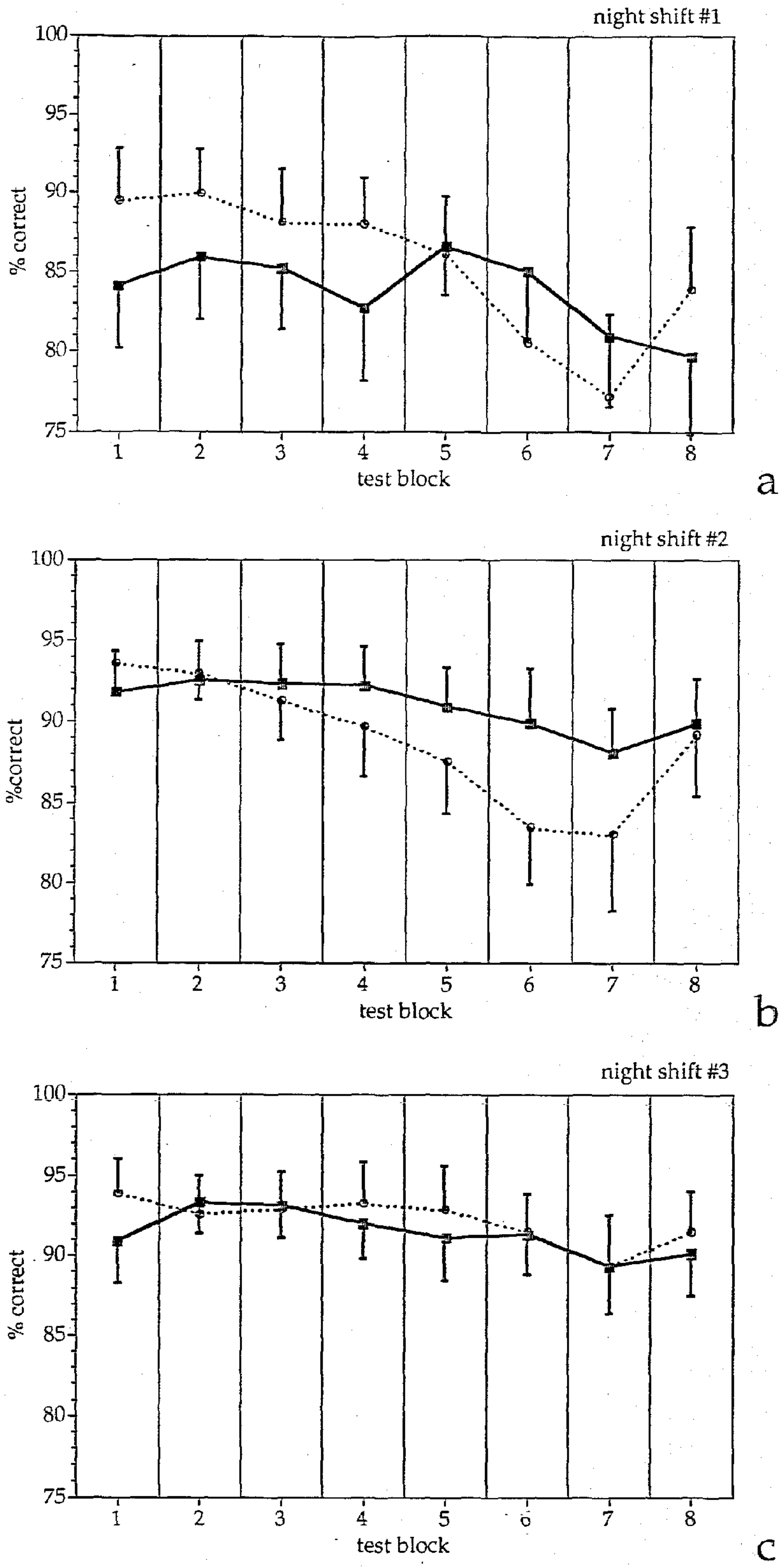
night shift #1
% correct
test block
a
night shift #2
%correct
test block
b
night shift #3
% correct
test block
c

Figure 4

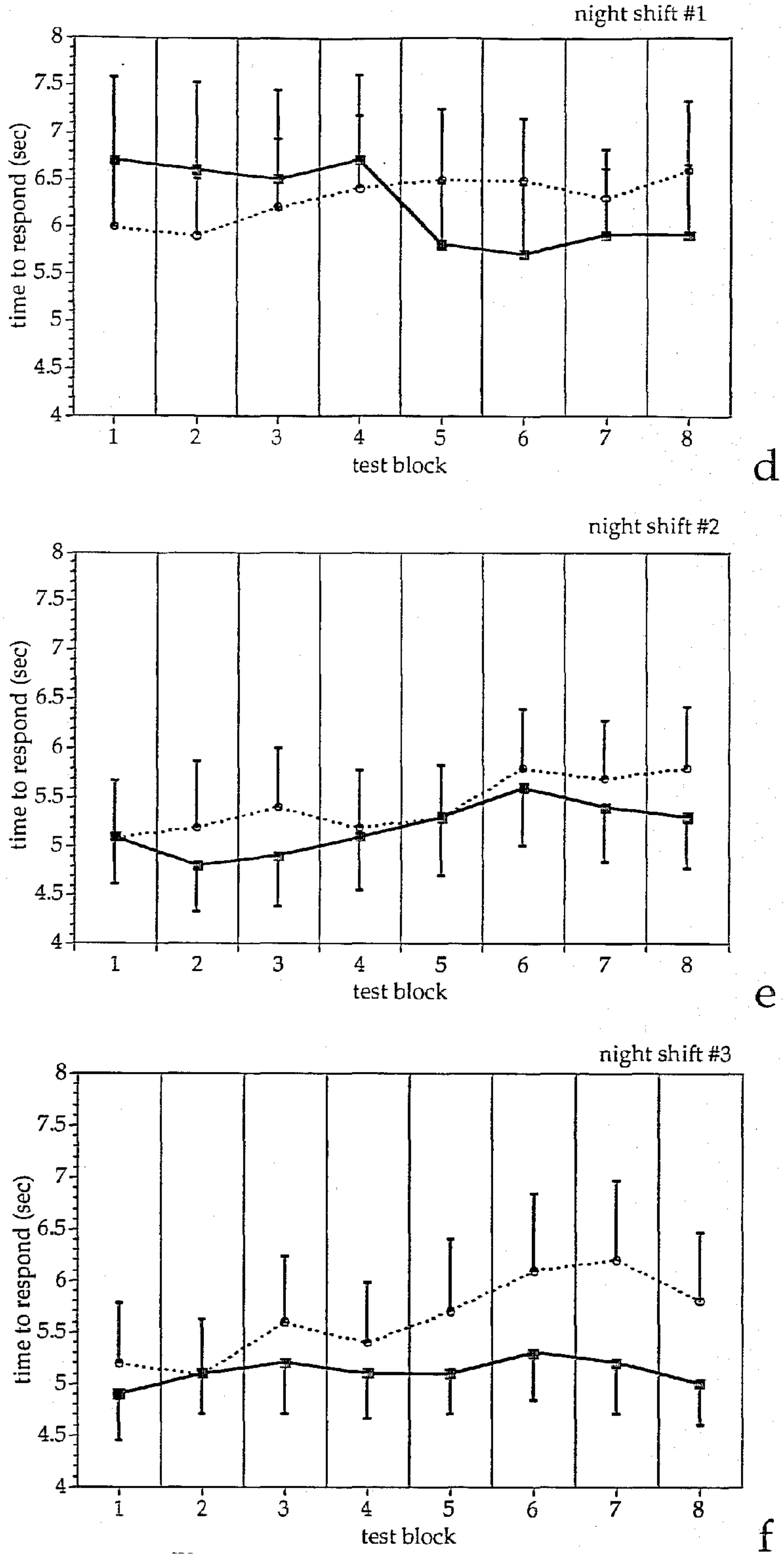
night shift #1
time to respond (sec)
test block
d
night shift #2
time to respond (sec)
test block
e
night shift #3
time to respond (sec)
test block
f

Figure 4