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16. Abstract Fifteen male paid volunteers (ages 20 to 28) were studied in three groups of five each. The first 4 days of the experiment they slept nights (2230 to 0600) and worked days. On the fifth night, they slept only 3 hours (2100 to 2400) before starting a 10-day period in which the wake-sleep cycle was altered by 12 hours. According to a subjective sleep survey, the total quantity and quality of sleep did not change significantly when the cycle was altered. According to the subjective fatigue index, the total fatigue for the awake periods was not significantly changed; however, the times within days for greatest fatigue were altered and 9 days were required for a complete reversal of the daily pattern. Of the physiological parameters measured, those making the most rapid response to stress rephased in the shortest period of time after the shift. From shortest to longest mean rephasal times, these were: heart rate, norepinephrine, epinephrine, potassium, sodium, internal body temperature, and 17-ketogenic steroids. Performance data based on the Civil Aeromedical Institute Multiple Task Performance Battery suggest the following: (1) There was evidence of diurnal variation during the preshift period. (2) There were decrements on the day of the shift following the short sleep period. (3) Performance during the first 3 days following the shift was relatively high for most of the day but was relatively poor in the final session of the day. (4) Performance on the fourth through sixth postshift days was average or above average for the experiment with relatively small variations among the five test sessions per day. (5) Performance on the seventh through ninth postshift days was below average for the experiment and showed some evidence of a return to a diurnal cycling pattern with a new peak period of performance that reflected the 12-hour shift in the wake-sleep schedule.

17. Key Words
Circadian rhythms, Complex performance, Heart rate, Rectal temperature, Urinary stress indicators, Wake-sleep cycles

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THE EFFECTS OF A 12-HOUR SHIFT IN THE WAKE-SLEEP CYCLE ON PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES AND ON MULTIPLE TASK PERFORMANCE

I. Introduction.

For many years biorhythms and the relationship between biorhythms and performance have generated a great deal of interest. In the past several years, this interest has intensified due to considerable changes in the human environment and work situation. The FAA has had a continuing interest in this area for two basic reasons: First, rapid air transportation across time zones often necessitates a change in the traveler's wake-sleep cycle that consequently results in disruption of his biological rhythm patterns. Second, the increasing number of tasks that must be performed on a 24-hour basis has resulted in an ever-larger work force of individuals who maintain, for varying periods, altered wake-sleep cycles because of rotating shift patterns.

The study being reported here was designed to evaluate the effects of alteration of the wake-sleep cycle by 12 hours on physiological and biochemical responses and performance and to supply information concerning the time required for adjustment of physiological rhythms to a new "steady state" when the wake-sleep cycle is altered.

II. Materials and Methods.

Fifteen males paid volunteers, ranging in age from 20 to 28 years, served as test subjects. They were tested in groups of five on separate occasions, and each group was confined to the laboratory area throughout the test period. Prior to the experiment each group spent approximately 75 hours in the laboratory for orientation and indoctrination. During this time they became proficient on the Civil Aeromedical Institute (CAMI) Multiple Task Performance Battery (MTPB)[2] and the Kügel apparatus and

TABLE 1. Schedule of MTPB Tasks Performed in 1-Hour Test Session

	Time in Minutes			
	0-15	15-30	30-45	45-60
Meters	X	X	X	X
Lights	X	X	X	X
Arithmetic			X	X
Problem Solving		X	X	
Pattern Identification	X	X		
Tracking	X			

Note: X indicates task active.

became acquainted with the experiment protocol. After a 2-day break they began the 15-day experiment period. On Days 1 through 5 the subjects worked during the day and slept at night (2230 to 0600) except on the fifth night, when they slept only 3 hours (2100 to 2400). On Day 6 the subjects began a new wake-sleep cycle, changed by 12 hours, in which they slept during the day (1030 to 1800) and worked at night. The subjects followed this day-sleep routine for 10 days.

The subjects were tested daily on the CAMI MTPB in five 1-hour sessions at 3-hour intervals. On preshift days the first session began at 0630 and the fifth session began at 1830 and ended at 1930. On the day of the time shift the subjects were tested at 0030, 0330, and 0630. After the time shift they were tested five times beginning at 1830 and ending at 0730 the following morning. Each session consisted of a fixed sequence of tasks as shown in Table 1. During each 15-minute subperiod, the subjects performed the indicated combination of tasks. The nature of the individual tasks and the performance measures derived from each are described in detail elsewhere[2] and will not be discussed here. The measure used to reflect the possible changes in performance was a composite score to which each of the measures from the individual tasks contributed equal variance. The grand mean of the composite score was set to equal 500 with a standard deviation of 10. For the purpose of analysis as well as the presentation of data, scores were combined over 3-day blocks. (The data for Days 1 and 2 were not used because of residual learning effects.) Namely, the performance data for the first daily session were averaged over Days 3, 4, and 5, and corresponding averages were computed for the four remaining daily sessions. The data for the three test sessions occurring on the day of the shift were treated individually. The data for the five daily sessions for Days 6 through 14 were also averaged in 3-day blocks; data for the final day were not used because of the likelihood of end-of-experiment effects.

The Kügel test estimates psychomotor performance. The "Kügelmaschine" is a horizontal rotating cylinder containing a row of five holes of graded sizes. Three sets of five steel balls corresponding in size to the holes in the cylinder were placed in a tray attached to the machine near the base of the cylinder. The test subject, seated in front of the tray, was instructed to pick up and insert, as rapidly as possible, the correct ball into a corresponding row of stationary holes lined up with those of the rotating cylinder. Cylinder speed was programed to accept 40, 50, 60, 70, 60, 50, and 40 balls per minute. Scores were automatically recorded on an attached strip chart. A stylus marked a short horizontal line only when a ball was dropped into a hole of the corresponding size. The final score was the sum of the scores at each cylinder speed.

Heart rate (HR) and body temperature (T_{re}) were measured hourly during the entire test period. Dry silver electrodes[12] attached to the CM_5 position were connected by wires to an Avionics Electrocardiocorder and HR responses were recorded on electromagnetic tape. Tape and batteries were replaced each 24 hours. Although HR was recorded continuously, only hourly averages were statistically analyzed. Rectal temperature was measured with a thermistor probe inserted 10 cm into the rectum. Values were read to the nearest 0.1° C with a portable bridge.

Urine was collected every 3 hours throughout the experiment period. The volumes were recorded, and aliquots were taken, preserved with boric acid and 1.2 N hydrochloric acid, and frozen for later biochemical analyses. Urinary catecholamines[6] and 17-ketogenic steroids[5] were determined by using Technicon Autoanalyzer systems. Sodium and potassium were measured with an Atomic Absorption-Emission Spectrophotometer (Instrumentation Laboratory, Inc., Model 353).

Subjective questionnaires included the 10-item Fatigue Checklist developed by Pearson and Byars[10] and the Sleep Survey developed at the USAF School of Aerospace Medicine that reflected the test subjects' judgment on both the length and quality of sleep the previous night.

A schedule of these events showing the times at which they occurred during the control period and also during the period after the change is presented in Figure 1.

III. Results.

A. *Subjective Forms.* According to results of the Sleep Survey, the alteration by 12 hours of

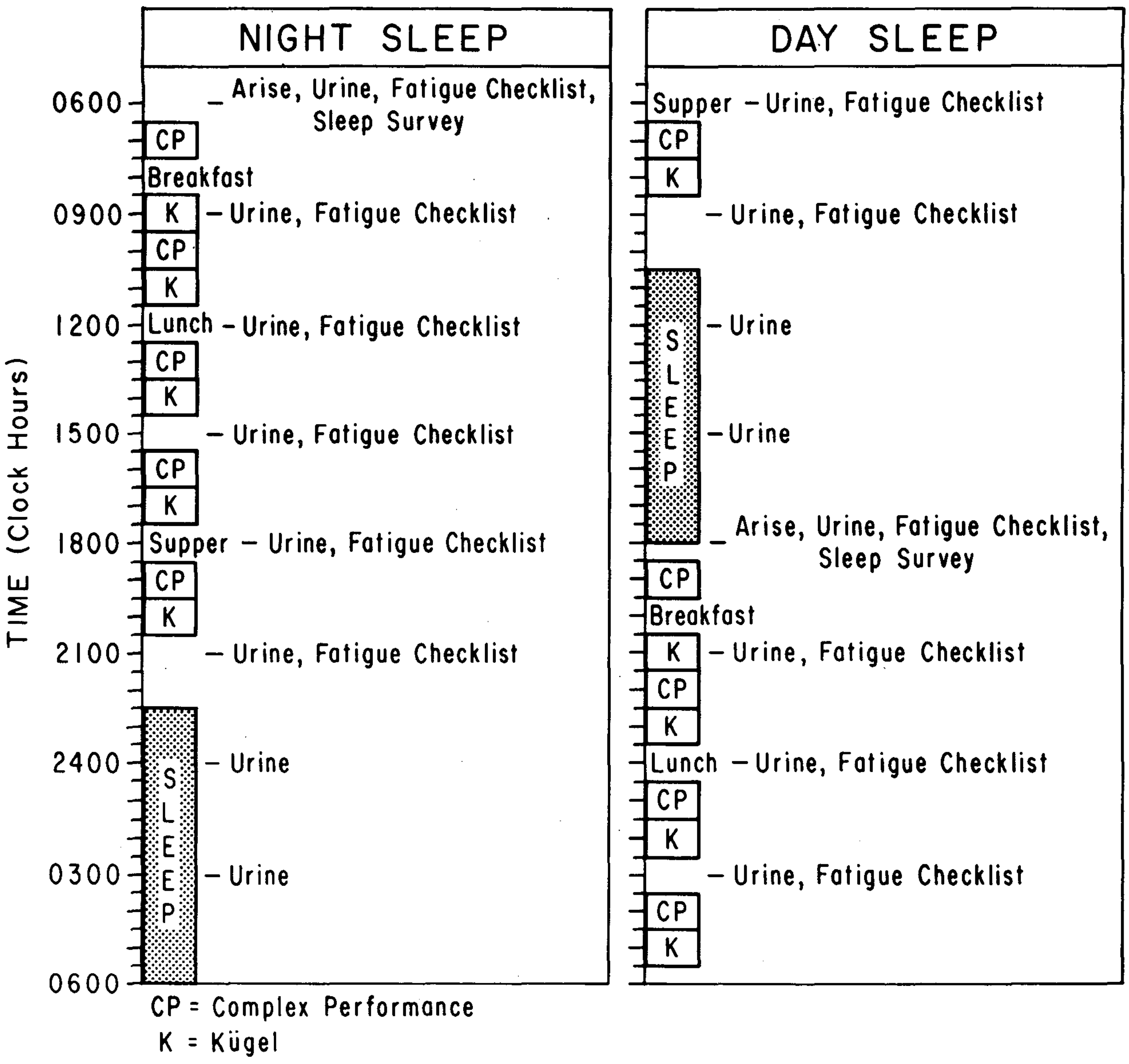

FIGURE 1. Schedule of events.

the wake-sleep cycle had little effect on either the total quantity or the quality of sleep. During the night-sleep segment the subjects slept, on the average, 91 to 96 percent of the sleep period with almost 50 percent being deep sleep. During the first day-sleep period all subjects but one reported sleeping the entire period. The average time asleep for all day-sleep periods exceeded 95 percent. Therefore, it would appear that all subjects adjusted quickly to the new time for sleeping.

The responses to the fatigue survey presented a different picture (Figure 2). These responses were recorded six times a day during the awake periods at 3-hour intervals, the first survey being completed upon awakening. The possible scores ranged from 0 (completely fatigued) to 20 (fully refreshed). The mean scores for the night-sleep period ranged from 10.2 to 10.4. The mean scores for the day-sleep periods ranged from 9.1 to 10.5. Although the daily means for night sleep and day sleep did not vary greatly, the time of day for lowest scores was different. After night sleep, the lowest scores were at 0600 each day, the first response of the day, indicating that the subjects did not feel fully refreshed

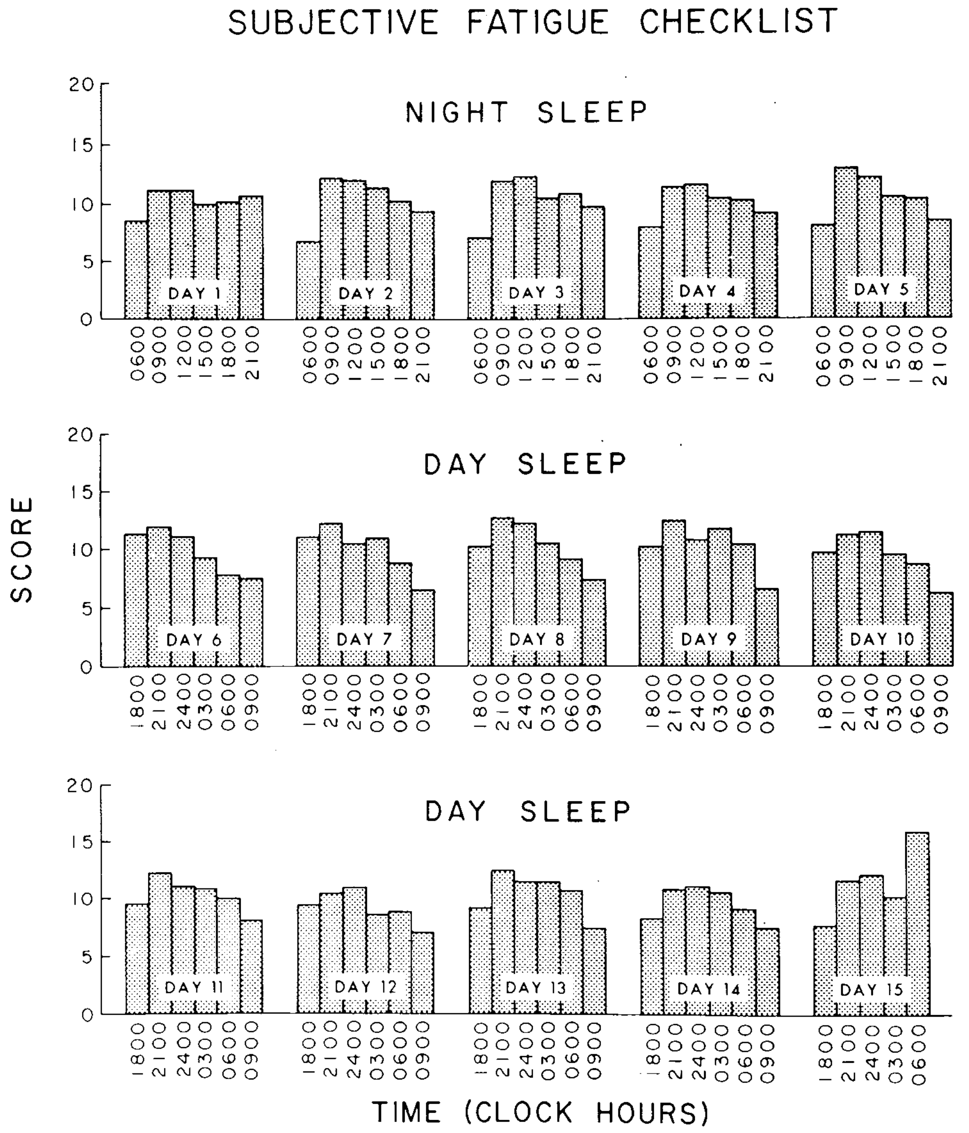

FIGURE 2. Mean score of Subjective Fatigue Checklist as a function of time of day for 15 consecutive days (n=15).

upon awakening. The next lowest score was the last response of the day (2100). The scores at 0900 and 1200 were similar and were the highest of the day. For the day-sleep periods, the first response upon awakening (1800) was relatively high the first day after the cycle change but showed a continuous, gradual decline each day to the end of the study. It was not until 9 days after the change that the first response upon awakening from day sleep reached the same level as the first response upon awakening from night sleep. The highest scores during the day-sleep periods were at 3 hours after awakening (2100), and the subjects consistently indicated the greatest feeling of fatigue at 0900, the last response before retiring. In general, the subjects felt more refreshed upon awakening from day sleep than from night sleep. However, they tended to indicate greater fatigue toward the end of the awake period when sleeping days. The greater the number of days spent at day sleep, the more closely the day-sleep responses approximated a 12-hour reversal of the night-sleep responses.

B. *Physiological Responses.* All physiological responses were measured at equal time intervals throughout the study and could thus be subjected to treatment by the summation-dial method.[7] The first four vectors of the dials are night-

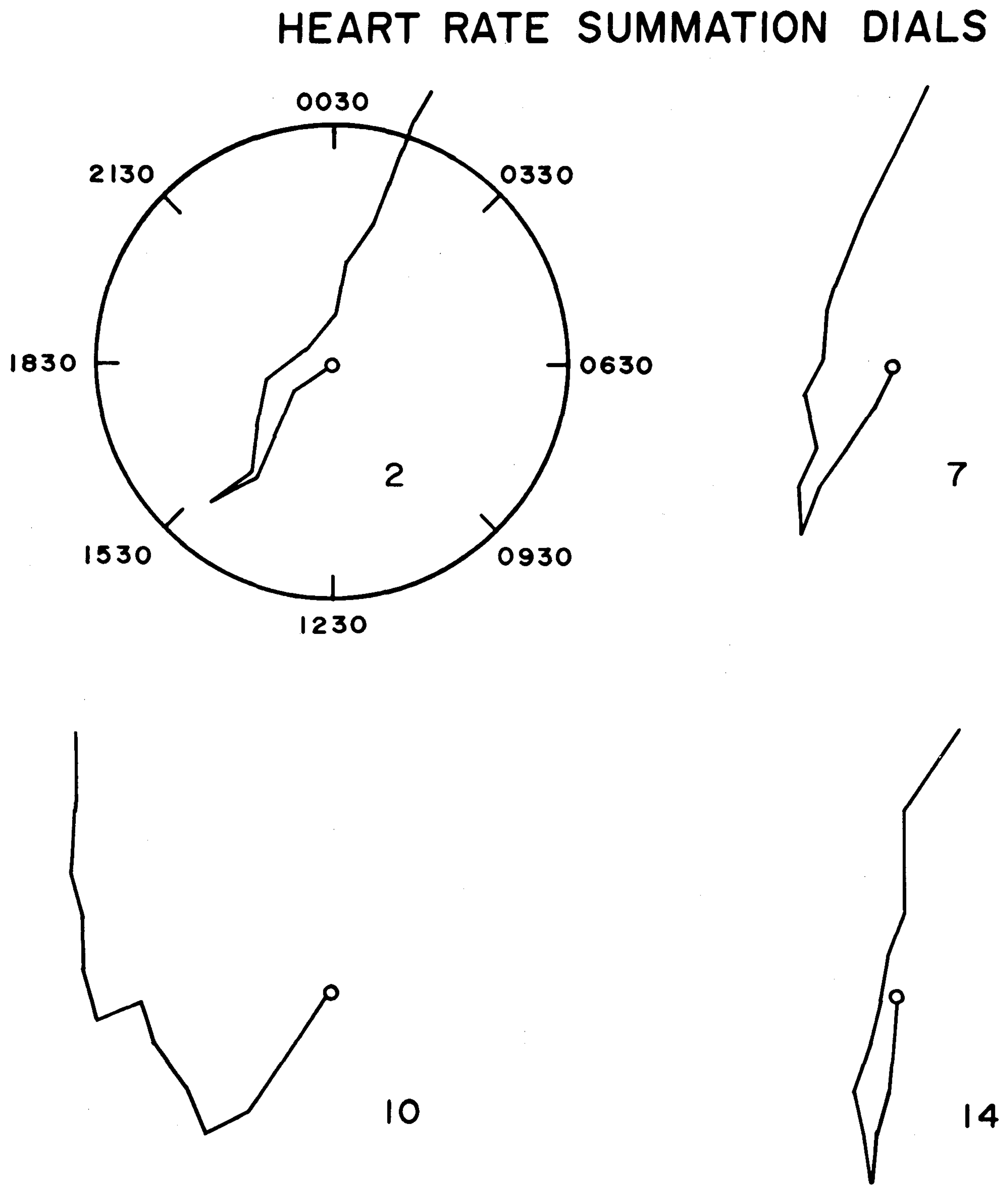

FIGURE 3. Heart rate summation dials for four representative subjects.

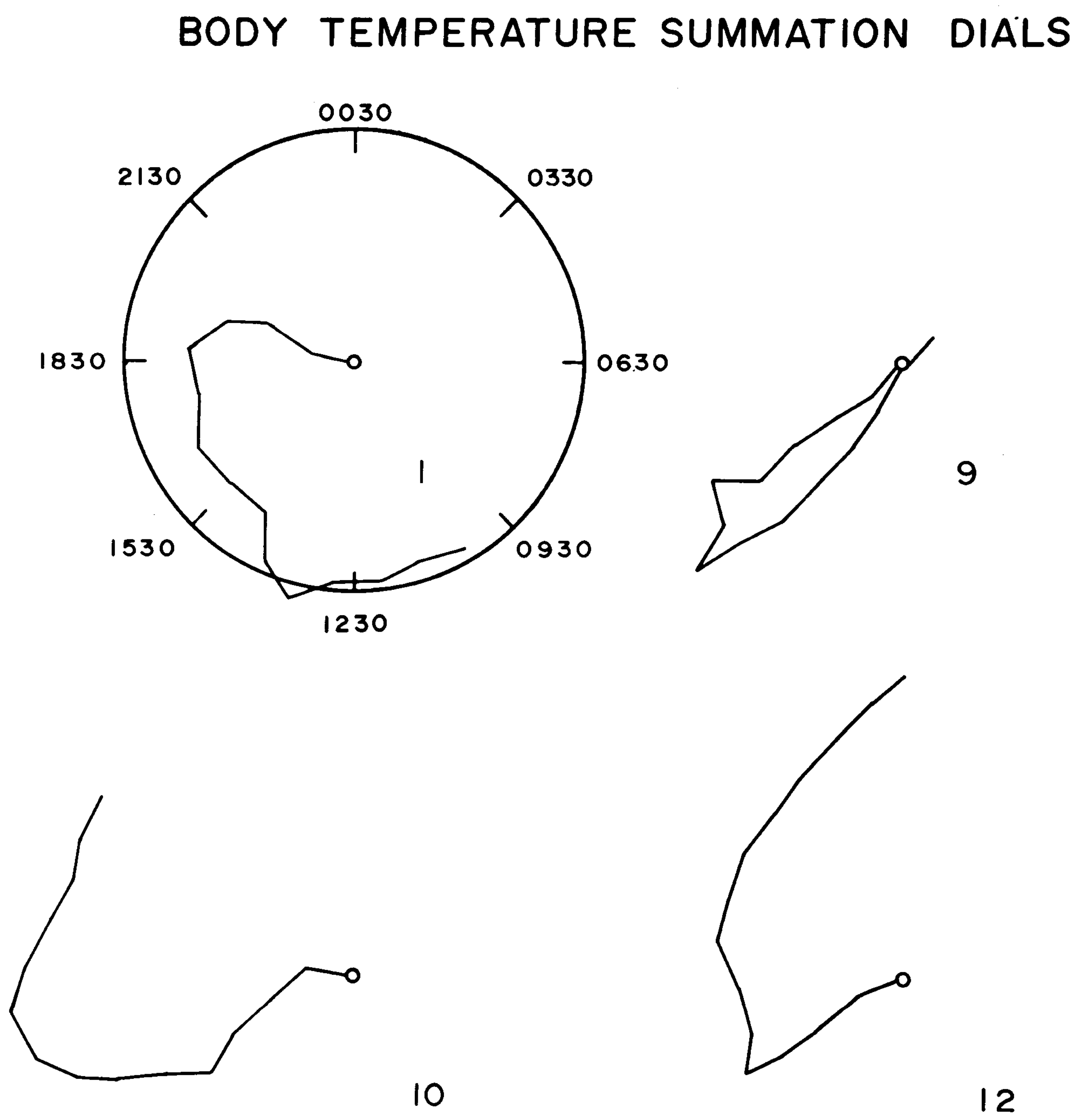

FIGURE 4. Body temperature summation dials for four representative subjects.

sleep time-of-peak values. The subsequent 10 vectors represent day-sleep values.

Figure 3 presents summation dials for four of the subjects for HR. The HR data indicate that all subjects made a fairly rapid adjustment to the shift change. The summation dials showed a 180° change in direction for day-sleep time-of-peak compared to night-sleep time-of-peak for all subjects but Subject 10. Although Subject 10 quickly established a new "steady state," the direction of change was only about 135° (9 hours) from the night-sleep responses. The complete reversal shown by the other three subjects depicted in this figure are typical of the responses of all other subjects. These data show less variation between subjects and more rapid adjustment than was anticipated.

Figure 4 presents the summation dials for T_{re}. In contrast to HR, T_{re} showed much variation between subjects. One subject quickly shifted

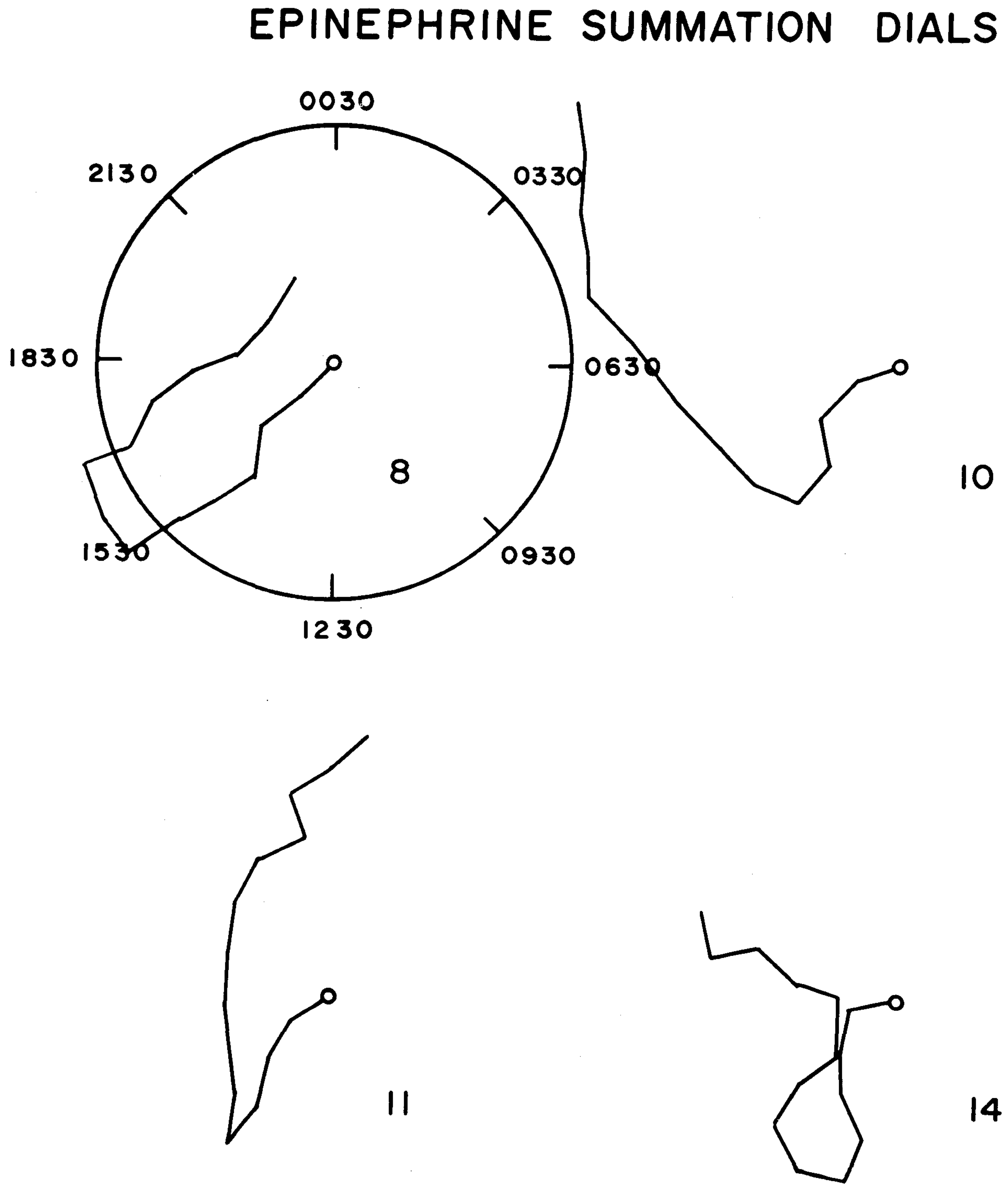

FIGURE 5. Epinephrine summation dials for four representative subjects.

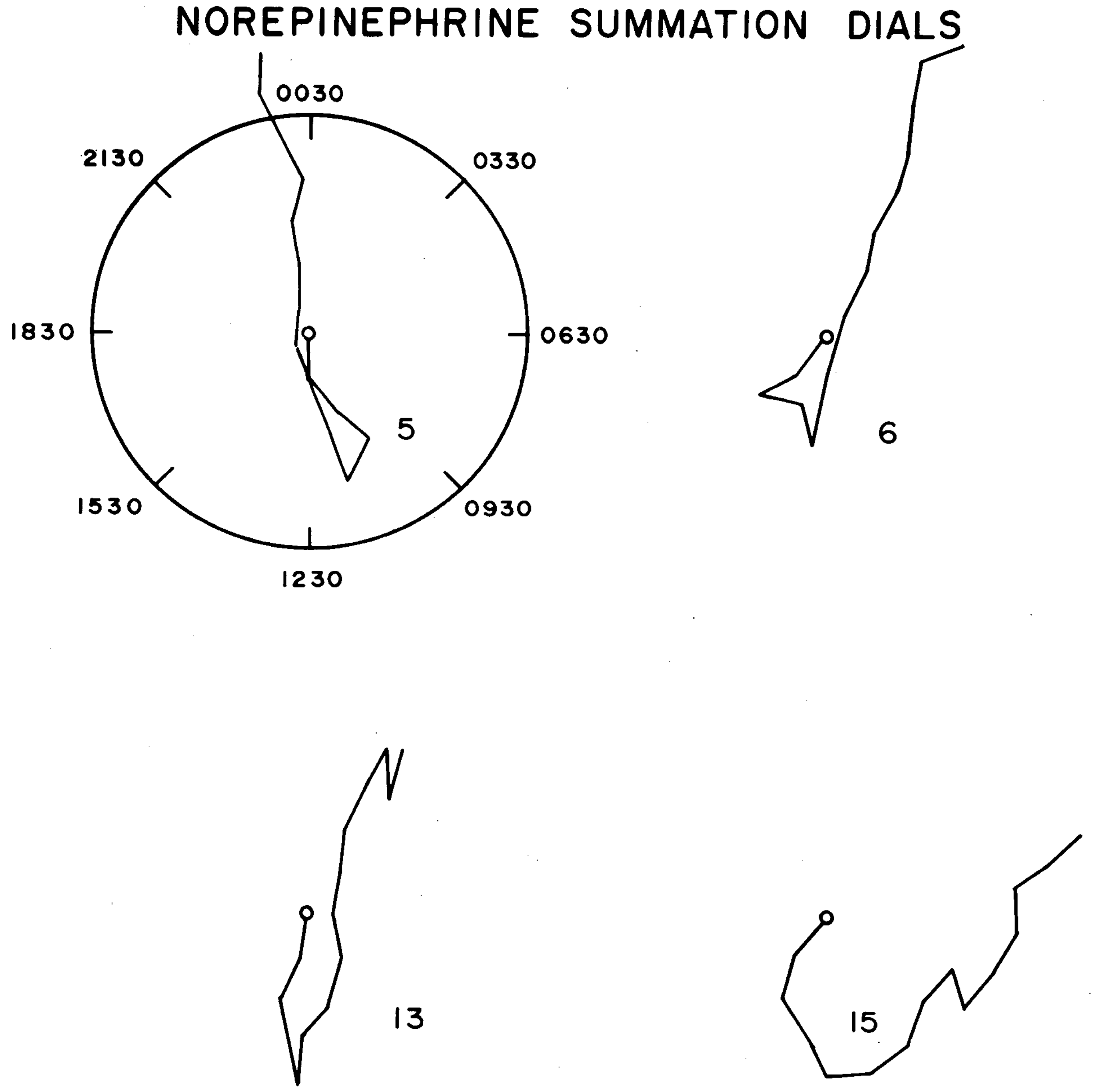

FIGURE 6. Norepinephrine summation dials for four representative subjects.

180° from baseline (2 days). Three subjects also shifted 180°, but less rapidly (3 to 4 days). Three other subjects, typified by Subject 9, made irregular loops but did rephase. Four subjects, as exemplified by Subject 12, made broad curves, rephasing over a 5- to 6-day period. One subject did not return a full 180° but appeared to be changing at the end of the experiment. The T_{re} of Subject 1 changed slowly but continuously and by the end of the 10th day after the change had shifted 14 to 15 hours. Subject 10 had a T_{re} response that, as was the case with his HR curve, reached a steady state of only about 135°.

The next five figures present the results of data obtained from urine excretion values. Urinary epinephrine (E) is presented in Figure 5, norepinephrine (NE) in Figure 6, 17-ketogenic steroids (17-KGS) in Figure 7, sodium (Na^+) in Figure 8, and potassium (K^+) in Figure 9. We did not anticipate that these data would be

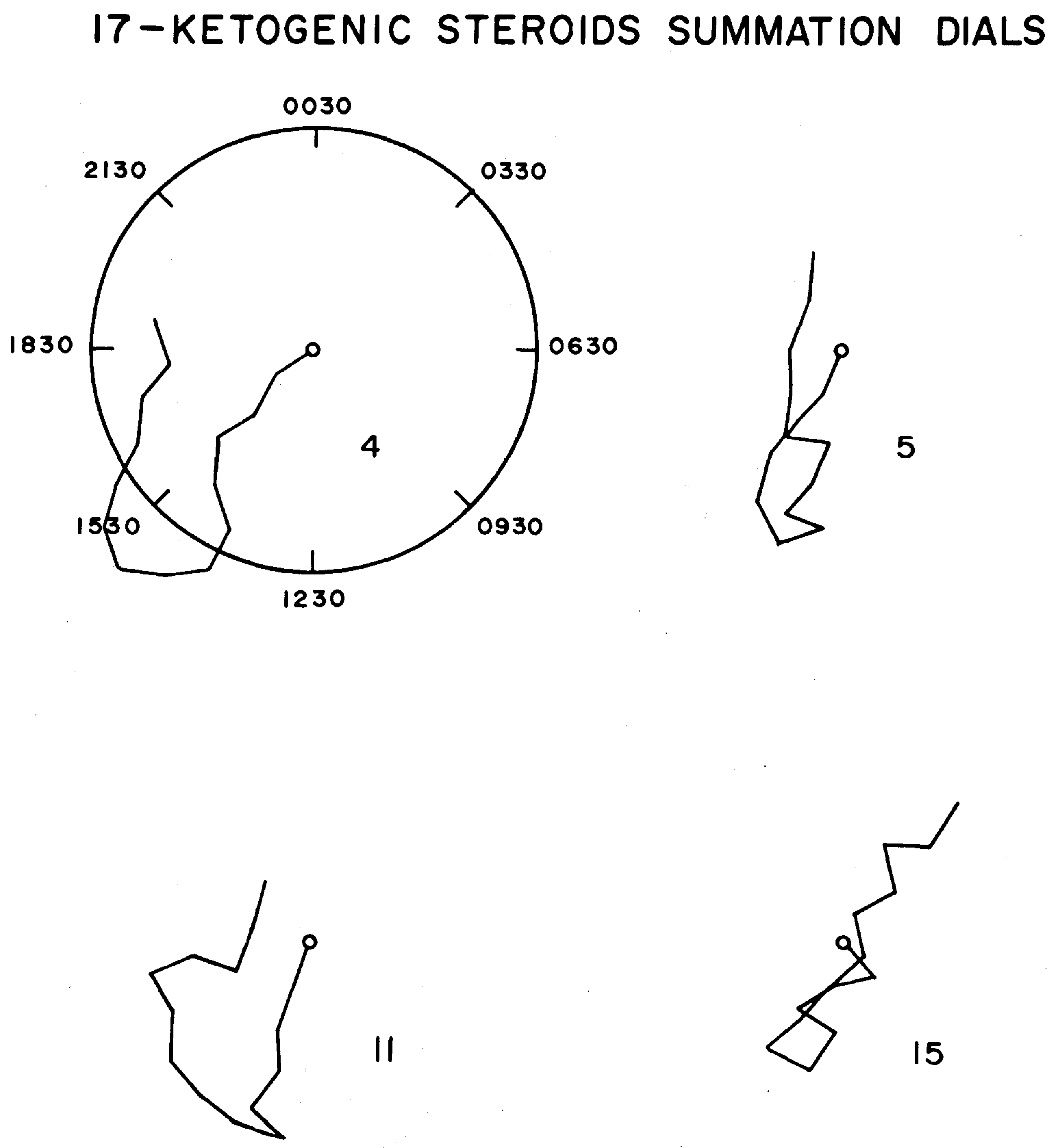

FIGURE 7. 17-Ketogenic steroids summation dials for four representative subjects.

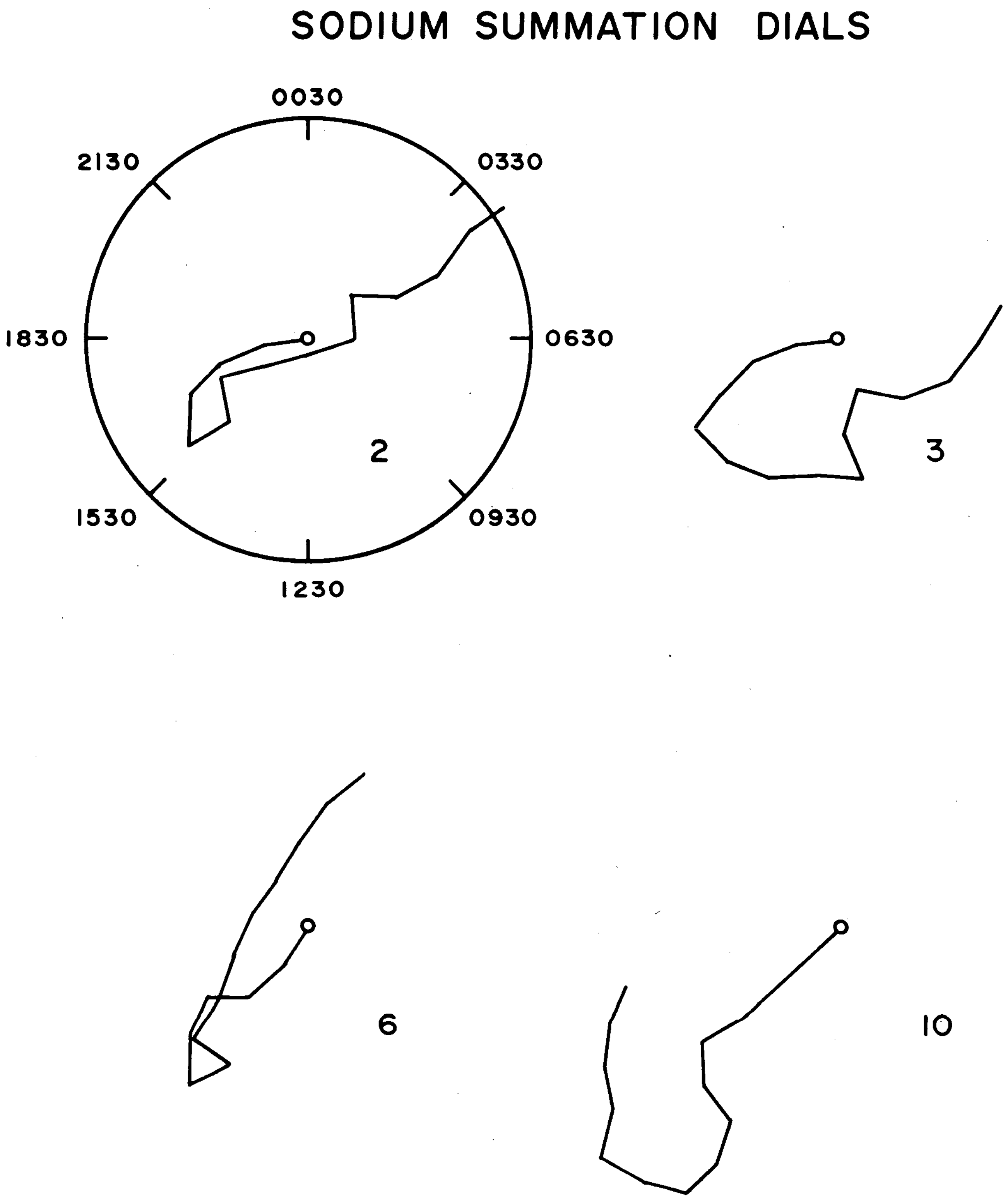

FIGURE 8. Sodium summation dials for four representative subjects.

POTASSIUM SUMMATION DIALS

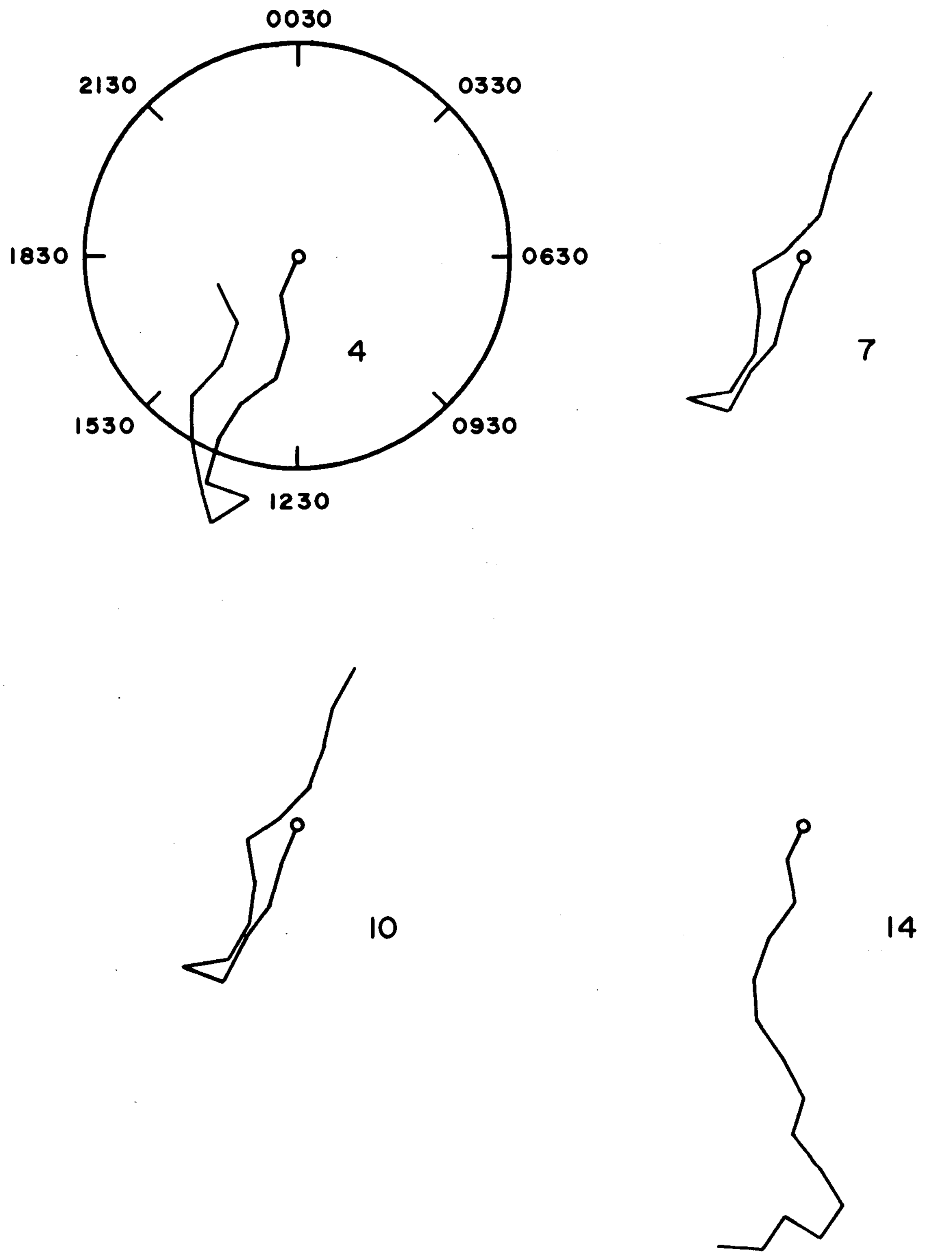

FIGURE 9. Potassium summation dials for four representative subjects.

as precise as the HR and T_{re} data, which were reported 24 times daily for a more precisely defined curve, as opposed to the urinary data, for which values were determined only eight times each day.

Table 2 indicates the number of days to rephasal, by subject, for each of the physiological parameters measured. The notation "IR" beside a number indicates incomplete rephasal; i.e., a new pattern was established but it was not 180° from the baseline days. The notation "RW" stands for random walk, or a pattern that was so variable as to establish no definable trend. All other numbers represent 180° reversal of the time-of-peak values. Table 3 presents the rephasal pattern, first by the parameter measured and then by subject. Subject 10 demonstrated IR for all parameters but NE. Subject 14 demonstrated RW for four parameters.

Fourier analyses were accomplished for the data by using three 96-hour segments. Each segment contained 97 data points for HR and T_{re} and 33 data points for the urinary constituents. Segment 1 was the last 4 days of the night-

TABLE 2. Number of Days for Rephasal

Subj. No.	HR	T_{re}	E	NE	17-KGS	Na^+	K^+
1	1	7	9 IR	2	9	9	9 IR
2	1	2	4	2	6	3	4
3	2	3	5	1	5	6	5
4	1	6	3	3	5	5	5
5	1	4	1 IR	1	7	3	3
6	2	4	1	1	6	4	4
7	2	4	3	5	8	5	3
8	2	4	5	2	5	5	5
9	2	4	5	4	6	4	3
10	1 IR	6 IR	1 IR	2	8 IR	7 IR	5 IR
11	1	5	1	5	9	5	5
12	1	5	4	6	7	3	3
13	2	5	7	1	7	5	5
14	1	8 IR	RW	RW	RW	5 IR	RW
15	1	6	1	6 IR	RW	3 IR	2
Mean	1.4	4.9	3.6	2.9	6.8	4.8	4.4
Range	1-2	2-8	1-9	1-6	5-9	3-9	2-9

IR = Incomplete rephasal (not 180°)

RW = Random walk

sleep (baseline) period, Segment 2 was the first 4 days after the 12-hour shift in the wake-sleep cycle, and Segment 3 was the last 4 days of the study (the 7th through 10th day after the reversal). The analyses were accomplished with 8 harmonics for the urine data and 48 harmonics for HR and T_{re}; the fourth harmonic was the 24-hour harmonic. In each of the seven parameters reported, the fourth harmonic exhibited the greatest percent of power and thus verified the 24-hour circadian rhythm. Table 4 presents the percent of power for the HR and T_{re} harmonics. Harmonics 9 through 24 and 25 through 48 were summed for simplicity of presentation. Table 5 gives the percent of power for the eight harmonics determined for the urinary constituents. These values are presented for the 96-hour night-sleep period. The electrolytes demonstrated the greatest percent of power for the fourth harmonic with NE having the least powerfully defined 24-hour periodicity.

Another facet, determined through the data analyses of the 96-hour segments, was the average time-of-peak for each of the 4-day periods.

TABLE 3. Summation-Dial Rephasal Patterns

By Parameter

	CR	IR	RW
HR	14	1	0
T_{re}	13	2	0
17-KGS	12	1	2
E	11	3	1
NE	13	1	1
Na^+	12	3	0
K^+	12	2	1
Totals	87	13	5

By Subject

Subj. No.	CR	IR	RW	Subj. No.	CR	IR	RW	Subj. No.	CR	IR	RW
1	5	2	0	6	7	0	0	11	7	0	0
2	7	0	0	7	7	0	0	12	7	0	0
3	7	0	0	8	7	0	0	13	7	0	0
4	7	0	0	9	7	0	0	14	1	2	4
5	6	1	0	10	1	6	0	15	4	2	1

CR = Complete rephasal (180° change)

IR = Incomplete rephasal (new steady state, less than 180°)

RW = Random walk (no regular pattern to change)

TABLE 4. Percent of Power of Harmonics for Heart Rate and Body Temperature (Based on 96 Hours of Baseline Data)

Harmonic	1	2	3	4	5	6	7	8	9-24	25-48
HR % Power	2.06	1.24	0.92	55.33	1.77	0.84	0.90	13.38	11.58	11.98
T_{re} % Power	2.39	2.53	3.08	51.56	2.19	1.44	0.83	10.84	13.40	11.80

These averages yield a different type of data than those determined for the daily time-of-peak ascertained for the summation-dial presentations. Tables 6 through 12 contain the time-of-peak for the 24-hour harmonic for each of the three 96-hour segments. For the baseline period (Segment 1), NE had the earliest time-of-peak (1302) and T_{re} was the last parameter to peak (1601). All other parameters peaked within the period between these two times. All parameters approached a 12-hour change in peak-response time between Segment 1 and Segment 3. The 17-KGS data, which demonstrated the longest average time to rephasal by the summation-dial technique, also demonstrated the least change between Segment 1 and Segment 3 (10 hours 35 minutes).

C. *Kügel Apparatus Performance.* The data generated from the Kügel task did not exhibit statistically significant differences as a result of the time shift. The automatic program designed by the manufacturer did not provide an adequately difficult task. The virtually perfect levels of performance achieved by the subjects on the Kügel apparatus tended to preclude the possibility of detecting changes in this kind of performance. Future studies should consider the difficulty parameter of this task in such a way that there will be room for performance changes.

D. *Complex Performance.* The data for performance on the MTPB are summarized in Table 13 and shown graphically in Figure 10. Significant differences (Chi square r) as a function of time of day (test session) were found only for the curve reflecting performance for the first 3 days after the shift. However, the time-of-day effect approached significance for the 3 days before the shift and the three sessions of the day of the shift. In the case of the data for the day on which the shift occurred, Sign tests were used to compare the differences among the three sessions, and these tests showed that the second and third sessions differed significantly from the first ($p \leq .02$) but not from each other. It would appear that, in the case of the data for the first 3 postshift days, the major effect was depressed performance during the fifth session of the day. The Sign test confirmed this in showing that performance in the fifth session differed significantly from that in the fourth session ($p \leq .02$).

TABLE 5. Percent of Power of Harmonics for Urine Constituents (Based on 96 Hours of Baseline Data)

Harmonic	1	2	3	4	5	6	7	8
17-KGS % Power	9.48	4.91	7.77	57.48	6.69	3.84	2.98	6.84
E % Power	9.39	8.00	5.43	55.15	6.22	5.26	2.60	7.95
NE % Power	16.41	12.34	8.61	33.06	8.60	3.93	5.08	11.96
Na^+ % Power	12.17	6.50	3.48	60.46	3.37	3.81	2.92	7.29
K^+ % Power	5.32	3.99	4.57	66.87	4.30	3.85	2.81	8.27

TABLE 6. Heart Rate

Subj. No.	Time of Peak Segment 1 (S1)	Segment 2 (S2)	Segment 3 (S3)	Difference (hr/min) S2 - S1	S3 - S1
1	1514	0138	0138	10/24	10/24
2	1429	0209	0135	11/40	11/06
3	1408	0005	0150	9/57	11/42
4	1337	0049	0125	11/12	11/48
5	1313	0016	0033	11/03	11/20
6	1308	2334	0020	10/26	11/12
7	1353	0027	0137	10/14	11/34
8	1343	2257	0104	9/14	11/21
9	1458	0040	0128	9/46	10/30
10	1435	2221	2357	7/26	9/22
11	1434	0025	0135	9/31	11/01
12	1358	0020	0111	10/22	11/13
13	1331	2344	0046	10/13	11/15
14	1328	0002	2356	10/34	10/28
15	1451	0140	0243	10/53	11/52
Mean	1408	0020	0111	10/12	11/03

The general pattern of the curves suggests the following: (1) Performance showed evidence of diurnal variation during the preshift period. (2) There were decrements on the day of the shift following the short (3-hour) sleep period. (3) Performance during the first 3 days following the shift was relatively high for most of the day but was relatively poor in the final session of the day. (4) Performance on the fourth through sixth postshift days was average or above average for the experiment with relatively small variations among the five test sessions per day. (5) Performance on the seventh through ninth postshift days was below the average for the experiment and showed some evidence of a return to a diurnal cycling pattern with a new peak period of performance that reflected the 12-hour shift in the work-sleep schedule.

IV. Discussion.

The sleep surveys indicated that the total quantity and quality of sleep did not change when the sleep cycle was altered by 12 hours. Also, the fatigue surveys indicated that total

TABLE 7. Body Temperature

Subj. No.	Time of Peak: Segment 1 (S1)	Segment 2 (S2)	Segment 3 (S3)	Difference (hr/min): S2 - S1	S3 - S1
1	1825	0900	0359	-9/25	9/34
2	1629	0016	0359	7/47	11/30
3	1450	0009	0232	9/19	11/42
4	1727	0101	0605	7/34	12/38
5	1639	0407	0321	11/28	10/42
6	1543	0151	0211	10/08	10/28
7	1722	2107	0240	3/45	9/18
8	1450	2343	0344	8/53	12/54
9	1529	0329	0225	12/00	10/56
10	1609	2034	0123	4/25	9/14
11	1550	2227	0200	6/37	10/10
12	1558	2339	0248	7/41	10/05
13	1504	2211	0214	6/67	11/10
14	1414	2024	0006	6/10	9/52
15	1550	0044	0258	8/54	11/08
Mean	1601	2247	0256	6/50	10/55

fatigue for the awake period was essentially unchanged. However, the times during which the subjects were most refreshed or most fatigued did vary. Nine days were required for the fatigue pattern to be reversed.

Realizing that the individuals rephased at different rates and their peak responses occurred at different times, we could not produce a mean response curve for the physiological data because averaging would tend to flatten the curves. We chose, therefore, to look at the physiological data of the subjects individually and report the total number of individuals yielding a particular type of response.

Those parameters that respond most rapidly to stress demonstrated the shortest rephasal times. Heart rate, which evidences almost immediate response during stress, rephases in the shortest time; rephasal was apparent on the first day after the shift for nine of the subjects and on the second day for the other six. This is probably a result of the highly structured protocol. All activities were imposed on the 12-hour shift in the same sequence. Participants were given little choice of activities, since the majority

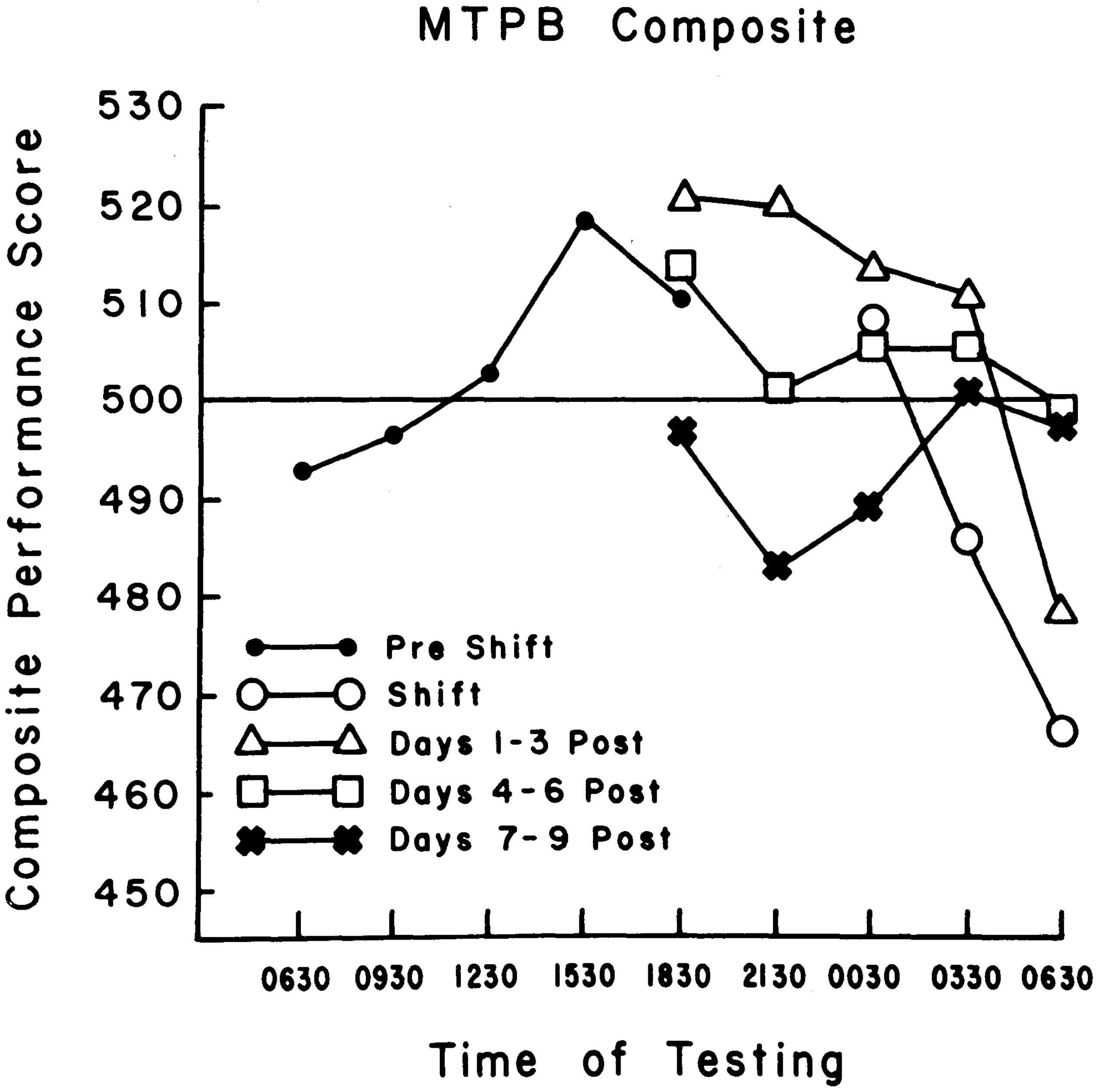

FIGURE 10. Multiple Task Performance Battery mean composite performance scores as a function of time of testing (n=15).

of the awake periods were occupied by activities directly associated with the test situation, and HR is highly influenced by activity levels.

The rephasal of catecholamines, which respond less rapidly to stress than does HR, required an average of 2.9 days for NE and 3.6 days for E. The catecholamines do, however, respond more rapidly to stress than do the other parameters measured and did demonstrate the next shortest rephasal times.

The times required for rephasal of K^+, Na^+, and T_{re} were intermediate, with means of 4.4, 4.8, and 4.9 days respectively. The K^+ data compare favorably with those reported by LaFontaine *et al.*[9] In that study the subjects were transported from Paris to Anchorage (11 time zones) and K^+ rephasal was accomplished in 5 days. The T_{re} data exhibited a high degree of variability, ranging from 2 to 8 days for resynchronization; however, 11 of the 15 subjects

TABLE 8. 17-Ketogenic Steroids

Subj. No.	Time of Peak Segment 1 (S1)	Segment 2 (S2)	Segment 3 (S3)	Difference (hr/min) S2 - S1	S3 - S1
1	1049	1516	2035	4/26	9/46
2	1352	0114	0100	11/23	11/08
3	1316	1020	0049	-2/55	11/33
4	1505	1738	0139	2/34	11/34
5	1434	0511	0047	14/37	11/13
6	1226	1848	0033	6/22	12/07
7	1407	1923	2338	5/17	9/31
8	1533	1835	0209	3/02	10/36
9	1428	1520	0037	0/52	10/08
10	1553	1230	2210	-3/21	6/16
11	1351	2140	0226	7/49	12/35
12	1247	1823	0013	5/36	11/26
13	1237	0325	2221	14/48	9/44
14*	1458	1048	1542	-4/10	0/44
15*	1620	0101	0239	8/41	10/19
Mean	1347	1913	0014	5/25	10/35

* By summation-dial method demonstrated a random walk and is not included in the mean values determined for this parameter.

rephased in 4 to 6 days. Our mean rephasal time of T_{re} is in fair agreement with one reported study[13] in which reversal of diurnal temperature rhythms occurred within 3 to 4 days after a 12-hour time shift. Other studies,[4 8 15] however, report a longer time for reversal. These differences might be accounted for by the fact that, in our experiment, the aspects of the temperature measurement considered for determining the time for rephasal were different from those considered in the experiments of others. In our appraisal, we considered only the time-of-peak response in determining rephasal; in other studies, phase angle was the chief consideration.

Of the parameters measured in this study, 17-KGS required the longest mean time for resyn-

TABLE 9. Epinephrine

Subj. No.	Time of Peak: Segment 1 (S1)	Segment 2 (S2)	Segment 3 (S3)	Difference (hr/min): S2 - S1	S3 - S1
1	1532	2152	2350	6/19	8/17
2	1450	0250	0244	12/00	11/54
3	1410	0038	0349	10/29	13/39
4	1459	0122	0310	10/23	12/11
5	1541	0112	0113	9/31	9/32
6	1304	2325	0025	10/21	11/21
7	1517	0022	0141	9/04	10/23
8	1520	0012	0404	8/52	12/44
9	1612	0220	0319	10/08	11/07
10	1410	2129	2348	7/19	9/38
11	1434	0022	0328	9/48	12/54
12	1752	0105	0253	7/13	9/01
13	1442	2211	0125	7/29	10/43
14*	1602	0009	2102	8/07	5/01
15	1410	0007	0051	9/56	10/41
Mean	1502	0015	0203	9/13	11/01

* By summation-dial method demonstrated a random walk and is not included in the mean values determined for this parameter.

chronization (6.8 days). This time is in line with the findings in other studies.[3 11 14]

In considering patterns for the individual subjects (Table 2), we noted that 10 of the 15 participants demonstrated a complete rephasal for all physiological parameters measured. Subject 5 was similar in response to the majority for all parameters except E. His E established a new steady state, as did his NE, in only 1 day, although it was not a complete 180° from baseline. This may indicate some error in baseline data. The 17-KGS data for Subject 15 produced no recognizable pattern and no suitable explanation is available at this time. Subject 1 demonstrated very long rephasal periods (9 days) for all but NE and HR with incomplete rephasal

TABLE 10. Norepinephrine

Subj. No.	Time of Peak: Segment 1 (S1)	Segment 2 (S2)	Segment 3 (S3)	Difference (hr/min): S2 - S1	S3 - S1
1	1607	0235	0059	10/28	8/52
2	1604	0232	0207	10/28	10/03
3	1119	0112	0149	13/53	14/30
4	1147	2235	0013	10/47	12/26
5	1216	2356	0000	11/40	11/44
6	1246	0125	0157	12/38	13/11
7	1219	0416	0323	15/57	15/04
8	1224	2322	2312	10/58	10/48
9	1649	0448	0153	11/59	9/04
10	1034	0101	0005	14/26	13/31
11	1314	2325	0035	10/10	11/03
12	1232	0216	2314	13/44	10/43
13	1232	0058	0208	12/26	13/36
14*	1200	0205	0047	14/05	12/47
15	1152	0440	0246	16/48	14/54
Mean	1302	0138	0110	12/36	12/06

* By summation-dial method demonstrated a random walk and is not included in the mean values determined for this parameter.

for these two parameters. Subject 10's data were unusual. Although a new steady state appeared to be established for all parameters, all but one were only 135°, or 9 hours, out of phase with night-sleep data. The indications were strong that this individual would not accomplish a 12-hour adjustment. Subject 14 produced data with no recognizable pattern for almost all parameters. From our observations of his behavior during the study, he did not appear to adjust well to the laboratory setting nor to the experiment protocol.

The general findings with the MTPB are consistent with the previous findings with respect to its sensitivity to time-of-day effects.[1] The pattern of changes in performance associated

TABLE 11. Sodium

Subj. No.	Time of Peak Segment 1 (S1)	Segment 2 (S2)	Segment 3 (S3)	Difference (hr/min) S2 - S1	S3 - S1
1	1129	1228	2236	0/59	11/07
2	1615	0501	0449	12/46	12/34
3	1458	0514	0420	14/16	13/22
4	1533	0812	0346	16/39	12/13
5	1644	0523	0455	12/39	12/11
6	1547	0200	0244	10/13	10/57
7	1639	0515	0526	12/36	12/47
8	1632	0052	0459	8/20	12/27
9	1518	0234	0307	11/16	11/49
10	1546	1339	0125	-2/07	9/39
11	1608	0257	0355	10/49	11/47
12	1746	0350	0429	10/04	10/43
13	1457	0046	0258	9/49	12/01
14*	1805	1069	0723	-7/24	13/18
15	1622	0054	0258	8/32	10/36
Mean	1544	0131	0328	9/47	11/44

* By summation-dial method demonstrated a random walk and is not included in the mean values determined for this parameter.

with the postshift phase of the experiment is suggestive of a sleep-loss phenomenon. This is seen directly in the data of the three sessions on the day of the shift when, in fact, there was an important decrease in the time available for sleep. The data for the first 3 full days following the shift suggest that the shift in the time at which performance was required did not have a detrimental effect except for the last session of the day. It is also relevant that this last session began 12½ hours after the end of the last sleep period. Thus, the "length of the workday" may have been responsible for the downturn of the curve of the preshift performance on the last daily session, and the poor performance on the last daily session of the first 3 days after the

TABLE 12. Potassium

Subj. No.	Time of Peak Segment 1 (S1)	Segment 2 (S2)	Segment 3 (S3)	Difference (hr/min) S2 - S1	S3 - S1
1	1056	1335	1902	2/38	8/06
2	1259	0119	0112	12/19	12/13
3	1329	0758	0225	18/29	12/56
4	1344	1934	0100	5/50	11/16
5	1338	0423	0026	14/44	10/47
6	1354	2301	2354	9/07	10/00
7	1419	0043	0159	10/25	11/41
8	1310	2125	0049	8/16	11/39
9	1304	0045	0056	11/41	11/52
10	1438	1427	2305	-0/11	8/28
11	1432	2147	0002	7/15	9/31
12	1325	0044	0105	11/20	11/41
13	1155	1045	2309	-1/10	11/14
14*	1344	1033	1740	-3/11	3/56
15	1328	2332	0022	10/04	10/54
Mean	1322	2200	0011	8/38	10/53

* By summation-dial method demonstrated a random walk and is not included in the mean values determined for this parameter.

shift may have been simply a substantial exaggeration of that effect. Although the subjective reports of the subjects did not suggest that the quality of sleep was appreciably poorer during the early days after the shift, any tendency in that direction would likely make the day seem somewhat longer to the subjects.

By the time that the fourth, fifth, and sixth postshift days had been reached, the subjects were able to maintain their performance at or above the average for the experiment. The depressed levels of performance on the seventh through the ninth days after the shift should not necessarily be regarded as suggestive of any di-

TABLE 13. Summary Data for Complex Performance

CLOCK TIME / PERIOD	0630	0930	1230	1530	1830	2130	0030	0330	0630	X^2_r	P
Preshift	493	497	503	519	511					9.23	≤.10
Shift							508	486	467	5.20	≤.10
Postshift											
Days 1-3					521	520	514	512	478	10.19	≤.05
Days 4-6					514	501	506	506	499	6.56	NS
Days 7-9					497	483	490	501	498	7.09	NS

rect effect of the time shift. Although subjects in this kind of experiment typically look upon the time shift as a challenge to their capabilities, once they feel that they have successfully met that challenge by demonstrating sustained, relatively good levels of performance, there is a strong tendency for a letdown to occur. The remainder of the experiment becomes, in effect, anticlimax. This would appear to be the most likely and the parsimonious explanation of the lowered performance levels during this final portion of the experiment. This rationale is, of course, directly related to our decision not to use the data from the final day of testing in the analysis. Although the shape of the performance curve for Days 7–9 is compatible with the inference that rephasal of performance had either occurred or was about to occur, the lack of statistical significance leaves the issue unresolved. Our experience in this kind of research suggests that subjects are typically unable to sustain their motivation for this long a period of removal from their normal social structure. This problem, coupled with the above-mentioned letdown phenomenon, makes the conduct of such experiments and the interpretation of results difficult.

V. Summary and Conclusions.

In our study of the effects of a 12-hour shift in the wake-sleep cycle, we made the following determinations: (1) According to the subjective sleep survey, the total quantity and quality of sleep did not change significantly when the wake-sleep cycle was altered. (2) According to the subjective fatigue index, the total fatigue for the awake periods was not significantly changed; however, the times within days for greatest fatigue were altered and 9 days were required for a complete reversal of the daily pattern. (3) Of the physiological parameters measured, those that make the most rapid response to stress rephased in the shortest period of time after the shift. From shortest to longest mean rephasal times, these were: heart rate, norepinephrine, epinephrine, potassium, sodium, internal body temperature, and 17-ketogenic steroids. (4) Performance data based on the MTPB suggest the following: (a) There was evidence of diurnal variation during the preshift period. (b) There were decrements on the day of the shift following the short sleep period. (c) Performance during the first 3 days following the shift was relatively high for most of the day but was relatively poor in the final session of the day. (d) Performance for the fourth through sixth postshift days was average or above average for the experiment with relatively small variations among the five test sessions per day. (e) Performance on the seventh through ninth postshift days was below average for the experiment and showed some evidence of a return to a diurnal cycling pattern with a new peak period of performance that reflected the 12-hour shift in the wake-sleep schedule.

The implications of these findings are as follows: (1) Individuals making a 12-hour alteration in the wake-sleep cycle should not perform critical tasks during the first awake period following the change. Performance decrements observed during this first period might be due to either the sleep loss or the initial adjustment to the new schedule, or both factors could be contributory. (2) After the first full sleep period following the change, subjects appeared to perform well even though the physiological and biochemical parameters measured were still adjusting to the change. (3) For the first week following the change in the wake-sleep cycle, individuals should not work longer than 8 hours continuously because performance deteriorates after that time. After the change, subjects appeared to fatigue more readily toward the end of the awake period than they did normally. This effect was evident for several days after the change.

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