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PHASE SHIFTS OF THE HUMAN CIRCADIAN SYSTEM AND PERFORMANCE DEFICIT DURING THE PERIOD OF TRANSITION:

III. North-South Flight

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I. Introduction.

Intercontinental jet flights designed to reveal the bidirectional effects of time displacement indicated[3-5] that for one physiological function, internal temperature, lag time of the primary phase shift appeared to be of the same extent. For other physiological functions, lag time was substantially different. Further, while significant increase in fatigue was reported during the periods of primary transition of both flights, performance deficit was occasioned by one flight but not the other.

In order to appraise the effects solely attributable to prolonged flight, a North-South flight was undertaken.

II. Method.

A. *Flight.* Originating in Washington, D.C., destination of the flight was Santiago, Chile. Time of departure was 1900 hours (EST), total time in transit was 18 hours, arrival time was 1300 hours (EST), and time displacement was 0 hour.

B. *Schedule of Assessment.* Periodic biomedical assessments were made in Washington, D.C., on alternate days during a week immediately prior to flight, during a 12-day period of layover in Santiago, and during the week following return to Washington, D.C. Throughout each assessment day, assessments were repeated at 0700, 1100, 1500, 1900, and 2300 hours (local time). During each of these five periods, different psychological functions were sequentially assessed by standardized procedures, and, simultaneously, physiological functions were measured. The time required for such a period was approximately 25 minutes.

C. *Assessments.* The following assessments were made.

1. *Rectal Temperature.* Internal body temperature was measured by a portable, indicating bridge circuit, calibrated to a thermistor rectal probe that was inserted to a depth of 10 cm, worn continuously throughout each assessment day, and removed only for bathing or evacuation. During the waking portion of the day, the subject read and recorded his own temperature to the nearest 0.1°C at 1-hour intervals; for the remainder of the day, a technician recorded the sleeping subject's temperature at the same interval.

2. *Evaporative Water Loss.* The method for quantitatively measuring skin-surface evaporative water loss has been described earlier.[1, 2] For each assessment period, a small plastic capsule[2] was sealed to the skin at the center of the left palm. Measurements of evaporative water loss from this area were made continuously throughout each assessment, evaluating both steady-state "basal" levels during rest before and after each assessment period and increased evaporative rates during identified assessment increments.

3. *Heart Rate and Respiratory Rate.* A lightweight, plastic and elastic chest strap was improvised to house three silver electrodes for heart-rate measurement and a mercury-in-rubber strain gage to monitor respiratory rate as a function of changes in chest circumference.

4. *Blood Pressure.* Both systolic and diastolic pressures were measured periodically throughout each assessment period by standard auscultatory techniques using an inflatable arm cuff and indicating sphygmomanometer.

5. *Reaction Time.* The speed of manual response to three successive presentations of a single auditory stimulus, three successive presentations of a single visual stimulus, six successive and randomly determined presentations of one of three possible visual stimuli, and one presentation of the single auditory stimulus was measured at each of the indicated times of assessment during each assessment day, as were the following psychological functions.

6. *Decision Time.* This was obtained for each assessment period by subtracting the mean time of responding to the three presentations of the single visual stimulus from the mean time of responding with the correct response to the six presentations of one of the three different visual stimuli. This value is taken to represent the average time required to "decide" which of the

three possible responses was the correct response to be made.

7. *Numerical Ability.* This was measured by a 90-item, 3-minute test requiring the addition of one- and two-digit numbers in sets of three (RPM Number Facility—NF—Alternate Forms, 1959 Edition published by the Hogg Foundation, University of Texas). The score represents a relatively factor-pure measure in speed and accuracy of simple addition.

8. *Subjective Fatigue.* The level of subjective fatigue was measured by checklists developed by the scale discrimination method and that were shown to reflect significantly the effects of perceptual-motor work and pharmacological treatment.[6]

9. *Critical Flicker-Fusion.* Thresholds were determined by computing the mean of three ascending measurements alternating with three descending measurements.

D. *Subjects.* Four healthy, adult, male volunteers were drawn from the professional and technical staffs of the Civil Aeromedical Research Institute. Following orientation and practice runs in Oklahoma City, they were transported to Washington, D.C., for a period of 9 days, the last 6 of which were devoted to preflight assessment. During all periods of assessment, preflight, overseas, and postreturn flight, the subjects were quartered in wards permitting supervision of activity. Finally, the subjects were instructed to maintain their daily living habits for both geographical locations in accordance with the local time.

III. Results.

A. *Primary Shift.* Figure 1 presents the results obtained during the preflight (Washington, D.C.) and postflight (Santiago) days of assessment. For each function, the plotted values are the means of the four subjects for each hour for rectal temperature; for each assessment period for palmar evaporative water loss, blood pressure, heart rate, and respiratory rate; and for each day of assessment in the case of the psychological functions. Preflight values represent the pooled means of the four subjects for the last 2 days of preflight assessment.

1. *Physiological Functions.* Circadian periodicity is seen most clearly for rectal temperature and heart rate as has been reported earlier.[3-5] Equally clear is the observation that the phase of the periods manifested by these functions does not evidence any shift following arrival in Santiago.

2. *Psychological Functions.* In contrast, considerable differences are revealed by the comparison of preflight and postflight curves of psychological functions. Of these, fatigue increases to the greatest extent but then returns close to the preflight level on Day +2. Decision time appears to increase (i.e., become slower) and to decline following Day +1. Whereas there is no change in reaction time on Day +1, reaction time is seen to be above the preflight level (i.e., become slower) on Day +2 and the remaining days in Santiago. In the instance of numerical ability, the increase noted during each day of assessment in Santiago actually represents greater proficiency. While critical flicker-fusion thresholds were determined, these are not reported owing to calibration difficulties experienced in Santiago. Of these differences in psychological function precipitated by the flight to Santiago, only the increment in fatigue was revealed to be statistically significant ($P=0.01$) by analyses of the variance attributable to replicated days of assessment.

3. *Comparison of Flights.* Data summarized in Figures 2 to 5 indicate the comparative effects of the East-West, West-East, and North-South flights upon primary phase shifts and performance deficit. Figure 2 reveals: (1) the extent to which rectal-temperature curves are out of phase initially with the local time of Manila and Rome, (2) the shifting of this function into phase with local time on successive days, (3) the number of days required for the completion of the phase shift, and (4) the lack of phase displacement of internal body temperature in Santiago.

Figure 3 shows that all flights resulted in an increase in the daily mean level of fatigue reported by the subjects, with the greatest increment being produced by the East-West flight and the smallest increment by the North-South flight. For each flight, the fatigue increment was found to be statistically significant.

Figure 4 indicates that the greatest increase in daily mean reaction time was produced by the East-West flight, which, moreover, was the only flight to have produced an increment in reaction time approaching statistical significance. Increase in daily mean decision time shown in Fig-

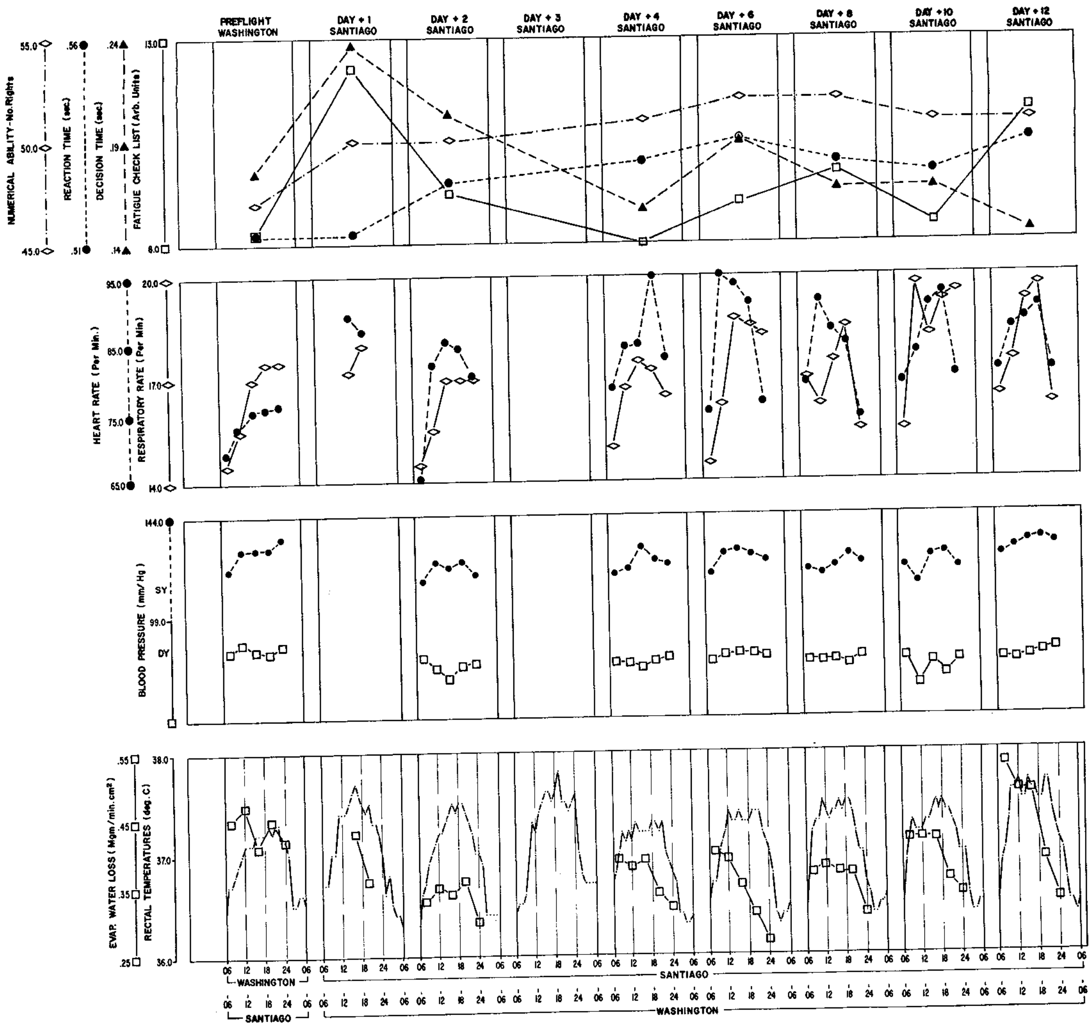

Figure 1. Mean plottings of data obtained in Washington, D.C. (preflight), and in Santiago (layover).

ure 5 followed each of the three flights but, again, only the increment effected by the East-West flight was found to be statistically significant.

B. Back Shift. Time of departure for the return flight to Washington, D.C., was 2130 hours (EST), total time in transit was 14-½ hours, and arrival time was 1200 hours. The first day of postflight assessment followed the day of arrival in Washington, D.C.

Figure 6 presents the obtained data, and, here, the basis for determining the effects of the flight consists of the values obtained during the last day of assessment in Santiago (Day +12). In this figure, there is no evidence of phase shifts of rectal temperature and heart rate, which is consistent with what was noted for the primary period of transition. The greater contrast between the two periods of transition is provided by the psychological functions). Day +1 in Washington, however, was the day following the day of arrival, whereas Day +1 in Santiago was the day of arrival, which may account for the fact that the increment in fatigue on Day +1 in Santiago was statistically significant, whereas the decrement seen for Day +1 in Washington is not.

IV. Discussion.

Bidirectional differences in time lag of the phase shifts shown by the physiological functions were obtained, but these differences did not reflect the

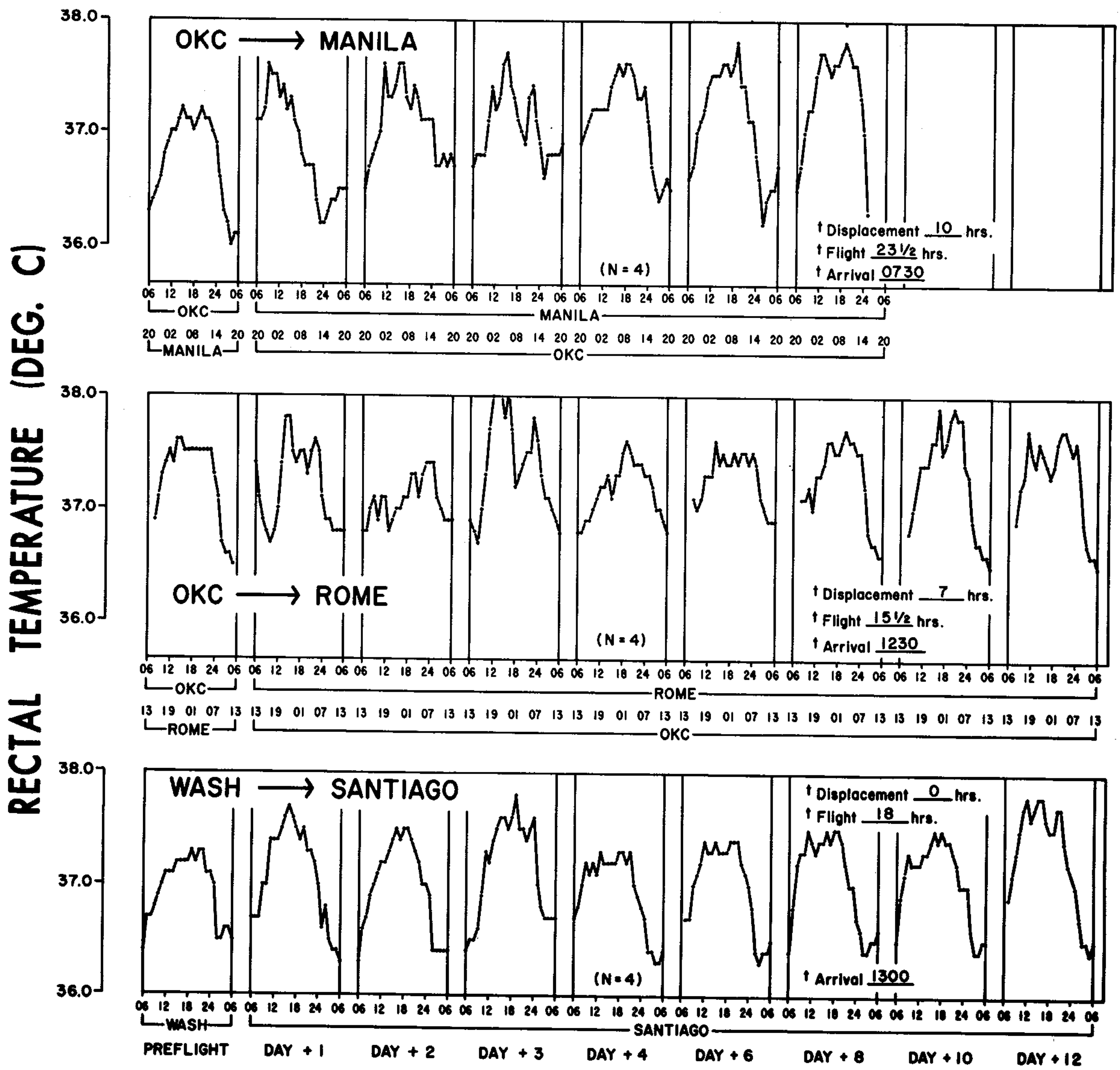

FIGURE 2. Comparison of rectal-temperature recordings obtained during preflight and primary periods of transition.

degree of consistency expected. For example, while the shifting of the rectal-temperature and heart-rate phases was closely associated during the transition period in Manila, pronounced dissociation was evidenced during the primary period of transition in Rome. This inconsistency may be attributable to effects of bidirectional time displacement, to individual differences, and/or to inherent variability of the physiological functions themselves. Nonetheless, one implication is readily apparent: A more critical evaluation requires more data.

In contrast, little difference in lag time was revealed by shifts of rectal-temperature periodicity, which was observed to be more consistently stable. For the East-West and West-East flights, lag time did not appear to differ by more than 1 day, suggesting that while bidirectional flights effect opposable phase displacements relative to local time, the time required for completion of the shifts of phase is approximately equal.

From this fact, impairment of psychological function produced by the East-West and West-East flights might be expected to be of equal ex-

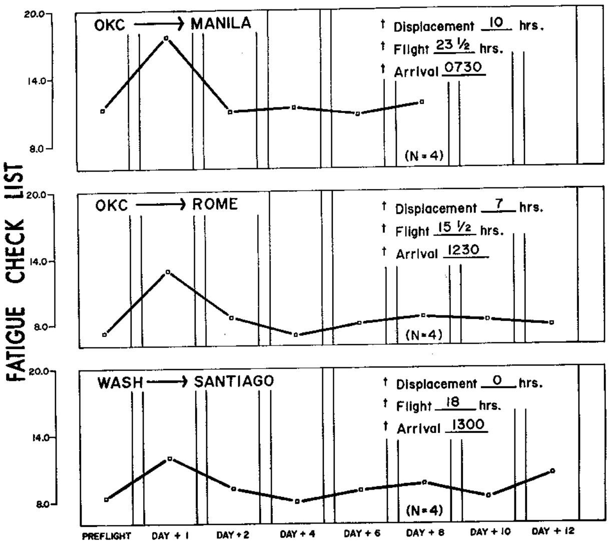

FIGURE 3. Comparison of daily means of subjective fatigue reported during preflight and primary periods of transition.

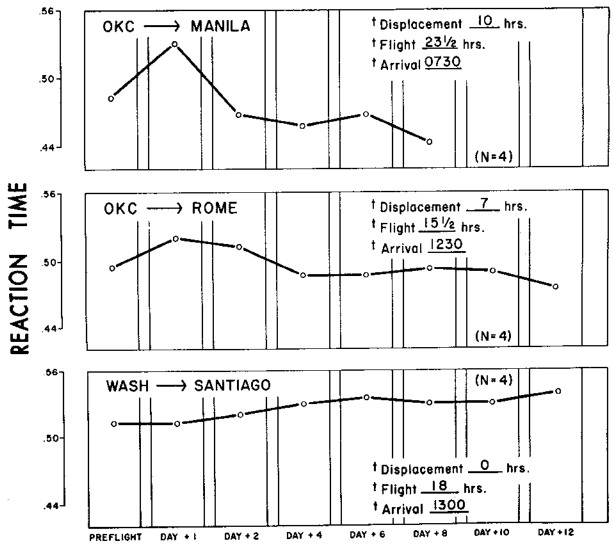

FIGURE 4. Comparison of daily means of reaction time measured during preflight and primary periods of transition.

tent; however, although both flights did produce a statistically significant increment in subjective fatigue, only the East-West flight produced a significant psychological deficit. Since the West-East flight was not followed by a similar short period of psychological deficit, the respective effects of time displacement and prolonged transit time may be questioned; more specifically, which of these two factors was primarily responsible for the deficit seen for the East-West flight?

To obtain relevant data it was necessary to conduct the flight being reported so that the single effects of prolonged transit time could be compared with the joint effects of transit time and time displacement. As has been seen, the psychological results of the North-South flight were similar to those of the West-East flight. Subjective fatigue was generated to a statistically significant extent but not psychological impairment. Consequently, the question still remains: Is the East-West deficit in psychological performance primarily attributable to time displacement and therefore a correlate of physiological phase shifts of circadian periodicity or to a total transit time of greater than 18 hours? Whatever the answer, one implication is apparent. Considering the extents of time displacements and total times in transit and the engendered increment in subjective fatigue, the degree and duration of psychological impairment was found to be far less than expected. This is of practical significance despite the claim that, since the subjects were passengers on the flights, greater impairment should not have been expected. Actually, the subjects were actively engaged with temperature readings, log recordings, etc. Further, the anecdotal reports that generally indicate marked psychological impairment do not differentiate between passengers and flight crews. Other explanations could be attempted, particularly in retrospect, but the data obtained from the three flights provide a basis for the following conclusion: Rapid translocation through many time zones does effect impairment of "well-being," but this is not accompanied by a commensurate change in the efficiency of basic psychological functions.

V. Summary and Conclusions.

At periodic intervals throughout the biological day, biomedical assessments were made for a week prior to jet flight to Santiago, for 12 days at Santiago, and for a week following return to Washington, D.C. From a comparison of these data

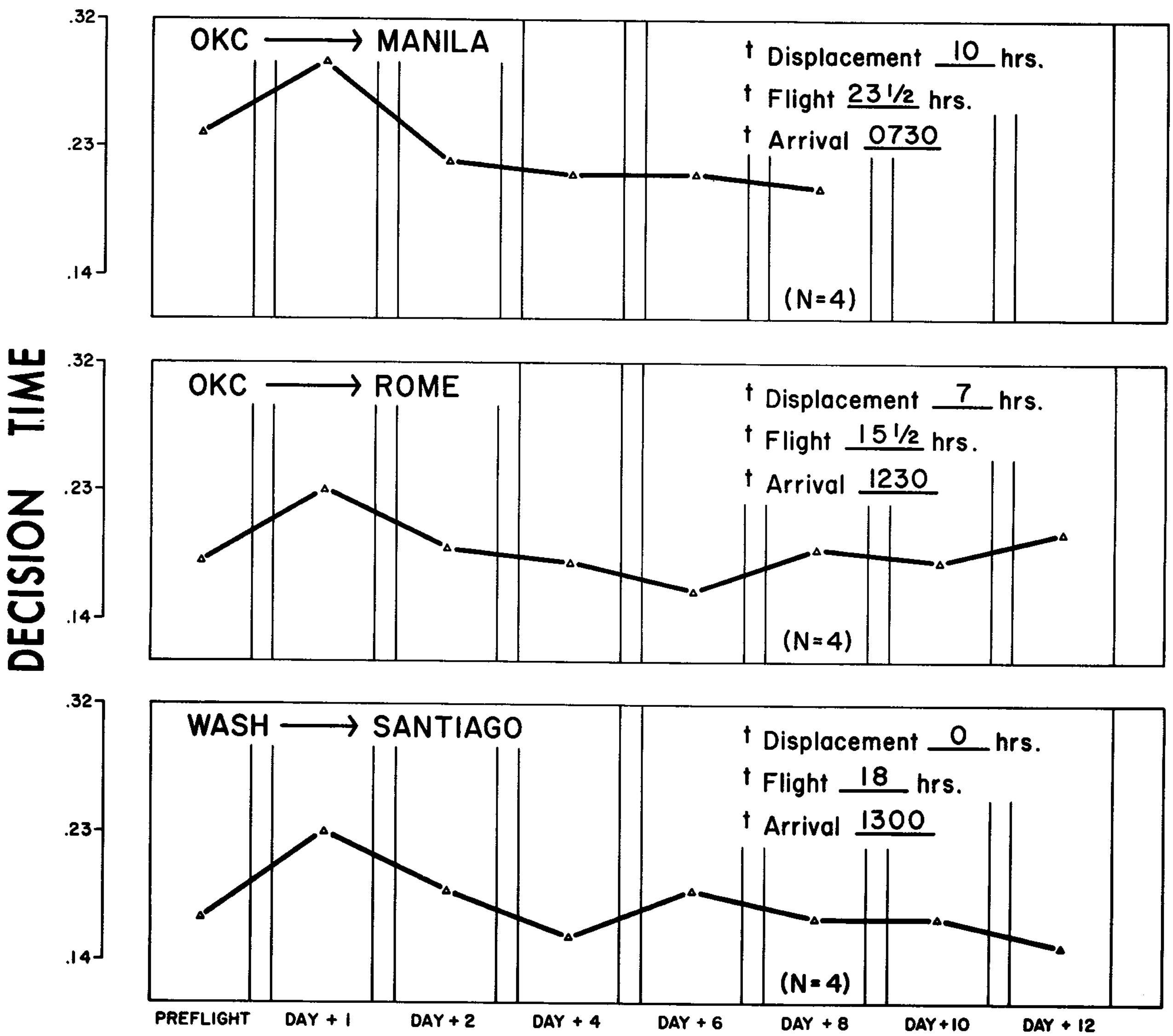

FIGURE 5. Comparison of daily means of decision time measured during preflight and primary periods of transition.

with those obtained from the East-West and West-East flights, the following conclusions were derived:

(1) While the East-West and West-East flights effected a primary shift of phase of circadian periodicity manifested by the physiological functions, the North-South flight did not.

(2) The North-South flight produced a significant increment of subjective fatigue, as did the other two flights.

(3) Significant impairment of psychological performance produced by the East-West but not the West-East flight was not shown by the North-South flight.

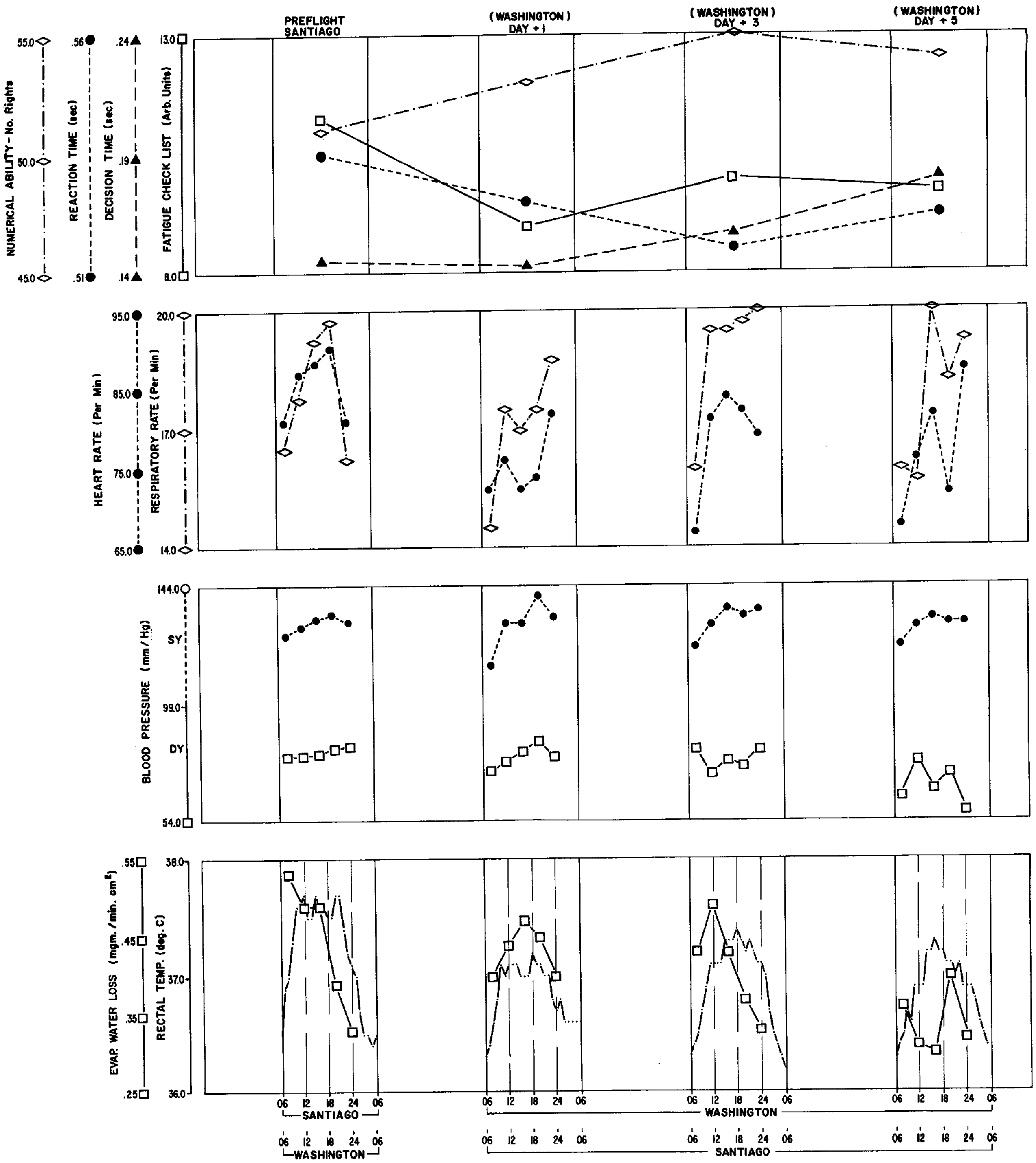

Figure 6. Mean plottings of data obtained on last day overseas (preflight) and following return to Washington, D.C.

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