AM 65-16

PILOT FATIGUE: INTERCONTINENTAL JET FLIGHT

1. Oklahoma City <——> Tokyo

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PILOT FATIGUE: INTERCONTINENTAL JET FLIGHT
Oklahoma City ←→ Tokyo

I. Introduction

Of the several conditions that produce pilot fatigue, one has been selected for specific and systematic experimental study. This condition, for the intercontinental-air-carrier crew, reputedly consists of the disruption of physiological day-night cycling occurring as a consequence of rapid translocation through many time zones. Due to biological lag time, these physiological readjustments can be expected to have the additional effect of attenuating recuperative processes. The predicted result, which in fact has been claimed by operating air crews, is an undesirable level of both acute and chronic fatigue.

Unfortunately, the scientific literature does not provide sufficient empirical, reproducible, or critically relevant information pertinent to these human physiological changes. Most of the experimental studies of human periodicity (e.g., Aschoff and Wever, 1962; Hauty, 1963; Kleitman, 1963; Lewis and Lobban, 1957) have been prompted by etiological considerations necessitating environmental conditions and controls such as to preclude fruitful extrapolation. Studies that have dealt directly with the problem concerned and that do permit extrapolation provide limited information. Such studies are few in number (Burton, 1956; Flink and Doe, 1959; Gerritzen, 1962; Sasaki, 1964), and with but one notable exception (Bugard and Henry, 1961) the respective subject population size was small, and, for the most part, only a single function rather than a spectrum of biological activities was assessed. The reason must not be attributed to any inadequacy on the part of the research investigators involved but, instead, to the costs and to the problems of logistics and experimental control likely to be encountered in such research.

Accordingly, a project consisting of a series of intercontinental flights was designed for the purpose of obtaining information that would reveal, firstly, the severity of the problem as it relates to the proficiency, reliability, and health of the pilot and, secondly, what might be done to mitigate those consequences found to be adverse or undesirable. The first phase of such flights will consist of an East-West, West-East, and a North-South round-trip jet flight that will permit a comparative analysis of bidirectional time-zone displacements and, by using the North-South flight as a "control," an appraisal of those effects solely attributable to prolonged flights.

To date, the East-West and the West-East flights have been completed. To be reported here are the findings obtained from a preliminary flight that, as a pilot study, served two purposes: determination of the feasibility of such a research project and collection of information relevant to the research problem concerned. In the case of the former, determinations had to be made of the logistical problems occasioned by the critically scheduled shipment of a considerable amount of scientific equipment, of the tolerance limits of human volunteer subjects, and of the reliability of assessment techniques. In the case of the latter, information was sought pertinent to those basic questions most obviously in need of initial and definitive answer:

A. What is the extent of time lag for biological phase shifts under these circumstances?

B. To what extent, if any, is proficiency adversely affected during the period of transition?

C. To what extent do individuals differ in lag time and adverse effects upon proficiency?

D. What is the extent and nature of differences manifested during the primary (Oklahoma City ⟶ Tokyo) and the back (Tokyo ⟶ Oklahoma City) shifts and their respective transitional periods?

Finally, one additional element of the rationale underlying this first phase of the project should be mentioned. The subjects were selected, not from intercontinental-air-carrier crews, but from a group whose daily habits of work and sleep were more representative of the general, adult, male population. The reason consists of the obvious need for a reference against which to compare the findings to be obtained from intercontinental-air-carrier crews during the second phase of the project. It is only with such a basis for comparison that an evaluation can be made of the respective roles of habituation that would act to attenuate fatigue-induced effects upon proficiency and health and of chronic exposure that could be expected to exacerbate such deleterious effects.

II. Method.

Following 3 consecutive days of biological assessment at Oklahoma City (preflight) conducted for the purpose of obtaining a reference of biological time set to Central Standard Time, subjects enplaned at 0810 hours (CST) for a jet flight to Tokyo. After 18 total elapsed hours, they arrived in Tokyo (1700 hours local time) and remained there for 10 days, during which biological assessments were repeated on alternate days beginning with the first full day in Tokyo. On the 11th day, subjects left Tokyo at 0930 hours (local time) on a jet flight and, after 17½ total elapsed hours, arrived in Oklahoma City at 1100 hours (CST) where they were subjected to 3 consecutive days of biological assessment (postflight) beginning with the first full day of their return.

The data to be reported include:

A. Rectal temperature—A calibrated rectal thermistor probe was worn by each subject continuously throughout the 24-hour day of assessment. During the waking portion of the day, the subject read and recorded his own temperatures to the nearest 0.1° C at 30-minute intervals on a portable meter. During the remainder of the day, a technician read and recorded at 30-minute intervals the temperatures of the sleeping subject.

B. Reaction time—The speed of the subject's manual response to (1) a single auditory stimulus, (2) a single visual, and (3) one of several possible visual stimuli ("multiple-choice") was measured at 4-hour intervals beginning at 0700 to 2300 hours for each day of assessment.

C. Critical flicker-fusion—Three ascending and three alternating descending thresholds were determined at the above times of assessment for each day of assessment. In indicating the highest rate at which this type of input can be adequately processed, these thresholds are generally considered representative of the state of efficiency of cerebral function, and, when used as an index of fatigue, an inverse relationship between the flicker-fusion threshold and hours of work (e.g., driving a truck) is generally reported.

D. Subjective fatigue—The level of fatigue perceived by the subject to be representative of his state of feelings was also measured at the above times of assessment during each assessment day by a scaled check list.

During the preflight and postflight periods in Oklahoma City, subjects were quartered in a clinical research ward. While in Tokyo, they were quartered in a hospital at a U.S. military base, which assured access to accustomed food. At both locations, subjects were instructed to conform to the extent possible to their own daily living habits, particularly the hours of local time for retiring to and arising from bed.

The subjects consisted of six male volunteers drawn from a medical-school population. The ages of three ranged from 19 to 23 years. Ages of the remaining three ranged from 40 to 48 years.

III. Results and Discussion.

A. Oklahoma City ⟶ Tokyo

Mean assessment values made during the 3-day preflight period in Oklahoma City and during the 10-day period in Tokyo are reported in Figure 1. In the case of rectal temperatures obtained during the 3 consecutive days of preflight assessment, means were computed for each hour for all subjects and for all 3 days. During the period in Tokyo, means were computed for all subjects for each hour of the 24-hour day of assessment. In the case of the remaining assessments, daily means were computed.

1. *Rectal temperature.* Examination of the preflight curve of rectal temperatures reveals the periodicity and amplitude of stored heat typically obtained under normal circumstances; i.e., a steady increase in internal temperature begins at awakening, peaks between 1400 and 1700 hours, and is followed by a steady decrease that continues to the beginning of the second biological day. Rectal temperatures during the first day in Tokyo appear somewhat less regular, apparently peaking about 4 or 5 hours out of phase with

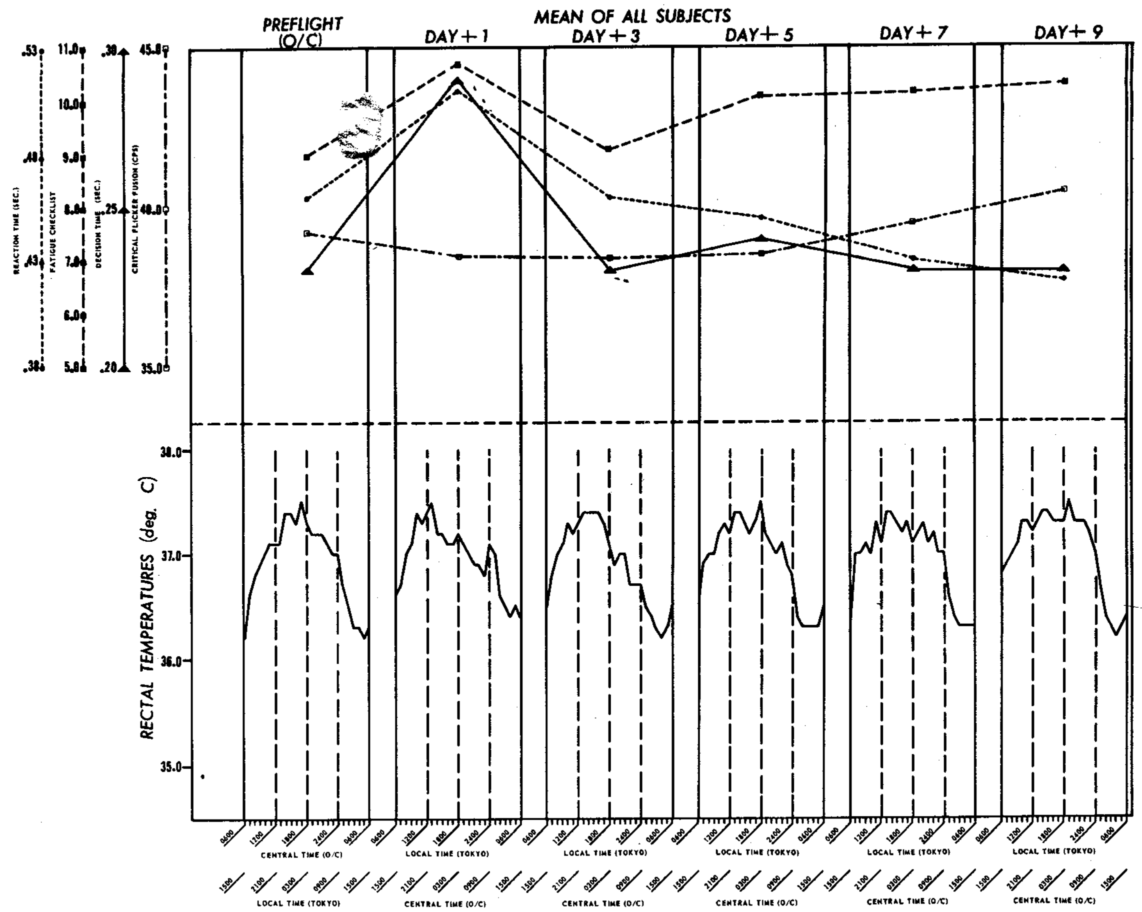

FIGURE 1. Mean values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion based upon six subjects assessed prior to flight and following arrival in Tokyo.

Tokyo time. By the third day in Tokyo, however, rectal temperatures appear to have shifted into phase with Tokyo time.

2. *Reaction time.* The values plotted for reaction time (solid circles) can be taken to represent the average speed with which the subjects reacted manually and appropriately to a variety of different stimuli throughout each given day of assessment. Using the preflight value (mean of all subjects of all 3 preflight days) as the basis for comparison, reaction time is seen to increase substantially (i.e., slower) during the first day in Tokyo. On the third day, reaction time is decreased (improves in speed) to a level comparable to that attained during the preflight period. An analysis of the variance attributable to replications (or days) reveals this difference in reaction time for these 3 days to be highly significant ($P < 0.001$). Throughout the subsequent days in Tokyo, reaction time continues to decrease. This gradual improvement in speed of reaction time is attributable, of course, to "practice effect," which, in turn, was occasioned by the necessity of having to include two subjects who did not have sufficient practice or training prior to the period of preflight assessment.

3. *Decision time.* The values plotted for what is termed decision time (solid triangles) were obtained by subtracting the mean time of reacting in a single way to a single visual stimulus from the mean time of reacting correctly in one of several possible ways to one of several possible stimuli (multiple-choice). The value thus obtained can be taken to represent the average time required by the subjects to "decide" which of the possible responses was the correct response to be made. Again, using the preflight plotted value as the basis for comparison, a considerably

greater amount of time is required for such decision during the first day in Tokyo. As in the case of reaction time, decision time is decreased to the preflight level on the third day and, for the most part, this level is maintained throughout the remainder of the period in Tokyo. In using the above-mentioned model for analysis of variance, the increase in decision time noted for the first day in Tokyo was significant at a $< 0.10 > 0.05$ level of confidence.

4. *Subjective fatigue.* The index of subjective fatigue was scaled from extremely fatigued to extremely alert; the higher the mean values obtained, the more fatigued the subjects felt themselves to be. From the curves seen thus far, subjective fatigue would be expected to be greater on the first day in Tokyo compared to the preflight period, and such is borne out. And, again, on the third day, the mean value has returned to the preflight level. This increment on the first day in Tokyo was also statistically significant ($P = < 0.05$), whereas the increment in fatigue seen to occur on the fifth day in Tokyo and to be maintained for the remainder of the period is not.

5. *Critical flicker-fusion.* On the basis of the literature, the curve of mean flicker-fusion thresholds was expected to take a form of agreement with the curves presented thus far. Had this occurred, a substantial decrease would have been noted for the first day in Tokyo, which would have been interpreted as a decrease in cerebral physiological efficiency. Since this did not occur, it must be concluded that physiological efficiency was either unaffected or improperly assessed. This conclusion was confirmed by the results of the analysis of the variance attributed to the day of assessment. To test these possibilities, a more precise and sophisticated instrument will be used on subsequent flights.

B. Tokyo ⟶ Oklahoma City

Figure 2 presents the mean assessment values obtained on the last day in Tokyo (day + 9), which can be regarded as the baseline for biological references set to Tokyo time against which to compare the mean values of data obtained following the return to Oklahoma City (days + 1, + 2, and + 3).

1. *Rectal temperature.* As compared to the baseline curve of rectal temperatures, the curve for the first day in Oklahoma City is seen to be in phase or very nearly so with Oklahoma City time, suggesting that the lag time of the back shift is much less than for the primary shift. In view of its obvious implications, it should be mentioned that this finding is in agreement with earlier speculation (Bunning, 1964, p. 58) and experimental evidence (Aschoff, 1958; Gerritzen, 1962). The depressed amplitude of the rectal-temperature curve during the first day back in Oklahoma City is surprising, since a corresponding thermal depression did not occur during any of the days in Tokyo. On the second day, however, the amplitude of the curve does approach more closely that of the baseline reference obtained in Tokyo and during the preflight period in Oklahoma City.

2. *Reaction time.* As noted in Figure 1, reaction time increases on the first day back in Oklahoma City and then decreases on the second day. The increment in this case, however, is less than that which occurred in Tokyo.

3. *Decision time.* In contrast with reaction time, decision time is seen to increase on the first day and to a greater extent on the second day in Oklahoma City. This latter might be partially explained by the following.

4. *Subjective fatigue.* A valid assessment of subjective fatigue is particularly difficult because of its susceptibility to the effects of other states of feelings. One such state, of course, is boredom and/or relief from boredom. Since the subjects did report boredom to have been generated by the long period of assessment in Tokyo, it is possible that the value plotted for the first day back in Oklahoma City may reflect relief from such boredom, followed by a return to this state on successive days. Debriefing of the subjects revealed boredom to be a matter of such importance that the regimen of assessment during subsequent flights was changed for the specific purpose of mitigating the effects of this state upon subject motivation.

5. *Critical flicker-fusion.* As in the case of Figure 1, little change in threshold value is to be seen.

IV. Summary.

A summary comparison of the primary and back shifts and their associated consequences is given by Figure 3. Under preflight are plotted the two bases of reference; i.e., the mean data

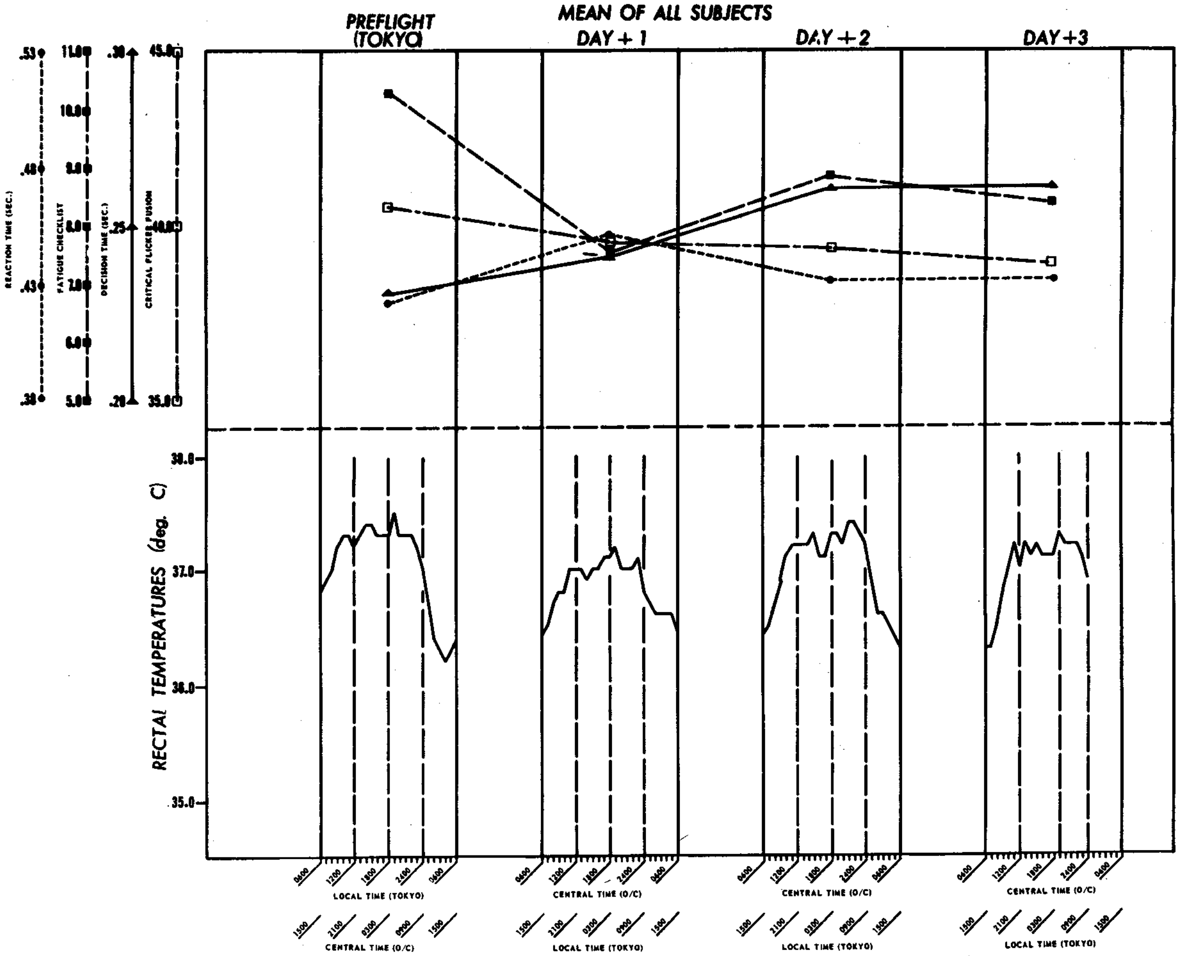

FIGURE 2. Mean values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion based upon six subjects assessed prior to return flight and following return to Oklahoma City.

values obtained in Oklahoma City during the preflight period (dashed lines) and during the last day in Tokyo (solid lines). Data are plotted in the next column (day 1) for mean values during the first day in Tokyo (dashed lines) and during the first day back in Oklahoma City. Mean values for the third day in Tokyo (dashed lines) and the third day back in Oklahoma City (solid lines) are plotted in the last column.

Since the subject group comprised two distinct age categories differing by about 20 years, the relationship of age with phase shifting (Kletitman and Kleitman, 1953) should be revealed clearly by the plotting of age-group means. An examination of Figure 4 reveals little difference between the rectal-temperature curves of the older (subjects 1, 2, 5—dashed line) and the younger groups (subjects 3, 4, 6—solid line) during the preflight period in Oklahoma City and the first and third days in Tokyo. On the fifth and seventh days in Tokyo, differences in phase and amplitude are indicated, but on the ninth day, the two curves again appear superimposable. For subjective fatigue, a considerable difference is revealed; the older group reports a higher level of fatigue the first day in Tokyo. Further, this higher level is shown up to the last day in Tokyo. Finally, it was expected that the older group would be characterized by slower reaction time, and this, as can be seen, is borne out. The question of interest was whether increase in reaction time during the transitional period would be differentially manifested; it is not evident to any appreciable extent. Differences in decision time are less consistent; the younger group shows the greatest increase during the first day in Tokyo and the greatest reduction during the subsequent days.

In contrast, Figure 5 reveals a profound difference in amplitude of the rectal-temperature curves of these age groups. Such a difference cannot be attributed to a consistent experimental error because of the technique selected for internal-body-temperature measurement (Mead and Bommarito, 1949). Since the level and diurnal pattern of human internal temperature has been shown to depend to some extent on subject voluntary activity (Vaughan and Adams, 1964; Sasaki and Carlson, 1964), it might be suggested that the impact of fatigue late in the experimental schedule resulted in a reduced level of physical activity, which in turn would be reflected in internal-temperature measurements. If this interaction were to occur, it is not unreasonable that its effect might be more manifest in the older subjects. It should be noted that the daily rectal-temperature patterns for the older subjects become progressively depressed, beginning with the preflight measurements in Oklahoma City when the subjects could not have been

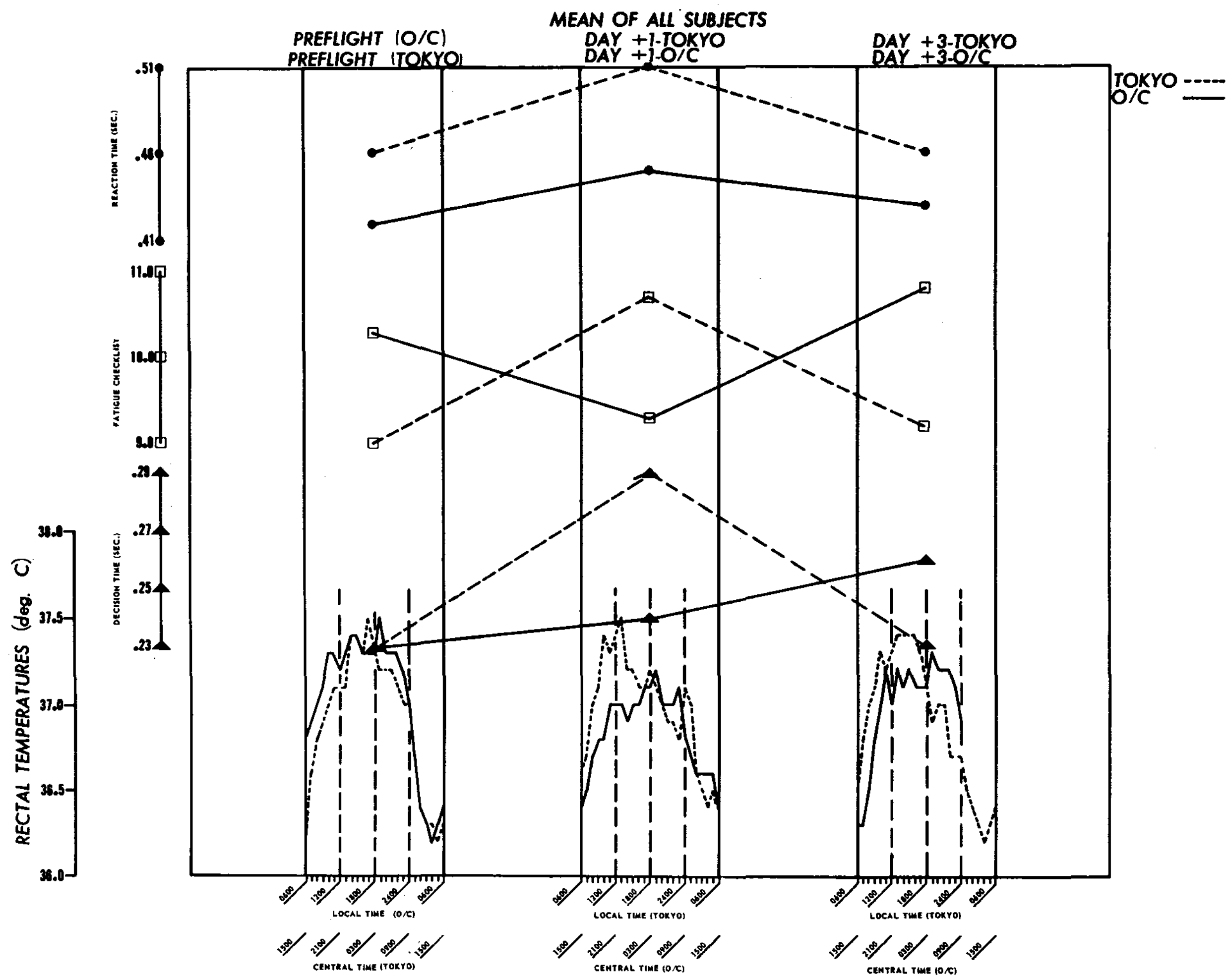

FIGURE 3. Comparison of mean values of rectal temperature, action time, subjective fatigue, and decision time obtained during the primary phase shift (dashed lines) with mean values of the same parameters during the back shift (solid lines).

fatigued, through the 9 test days in Tokyo (Figure 4). The depression of the rectal-temperature curves for the three older subjects more closely follows the pattern of the accumulated fatigue reported by the group than for the younger team members. Nonetheless, until measurements of subject activity levels in terms of whole-body metabolism or heart rate are made simultaneously with internal temperature in a test schedule paralleling the one reported here, this question must remain open.

Lastly, the expected differences in reaction time and decision time are again manifested except for the last day. For this day, the performance of one of the three subjects was responsible for the marked increase in the mean values.

V. Conclusions.

From what has been presented and from inspection of curves prepared for each individual subject (Appendix) certain conclusions can be derived.

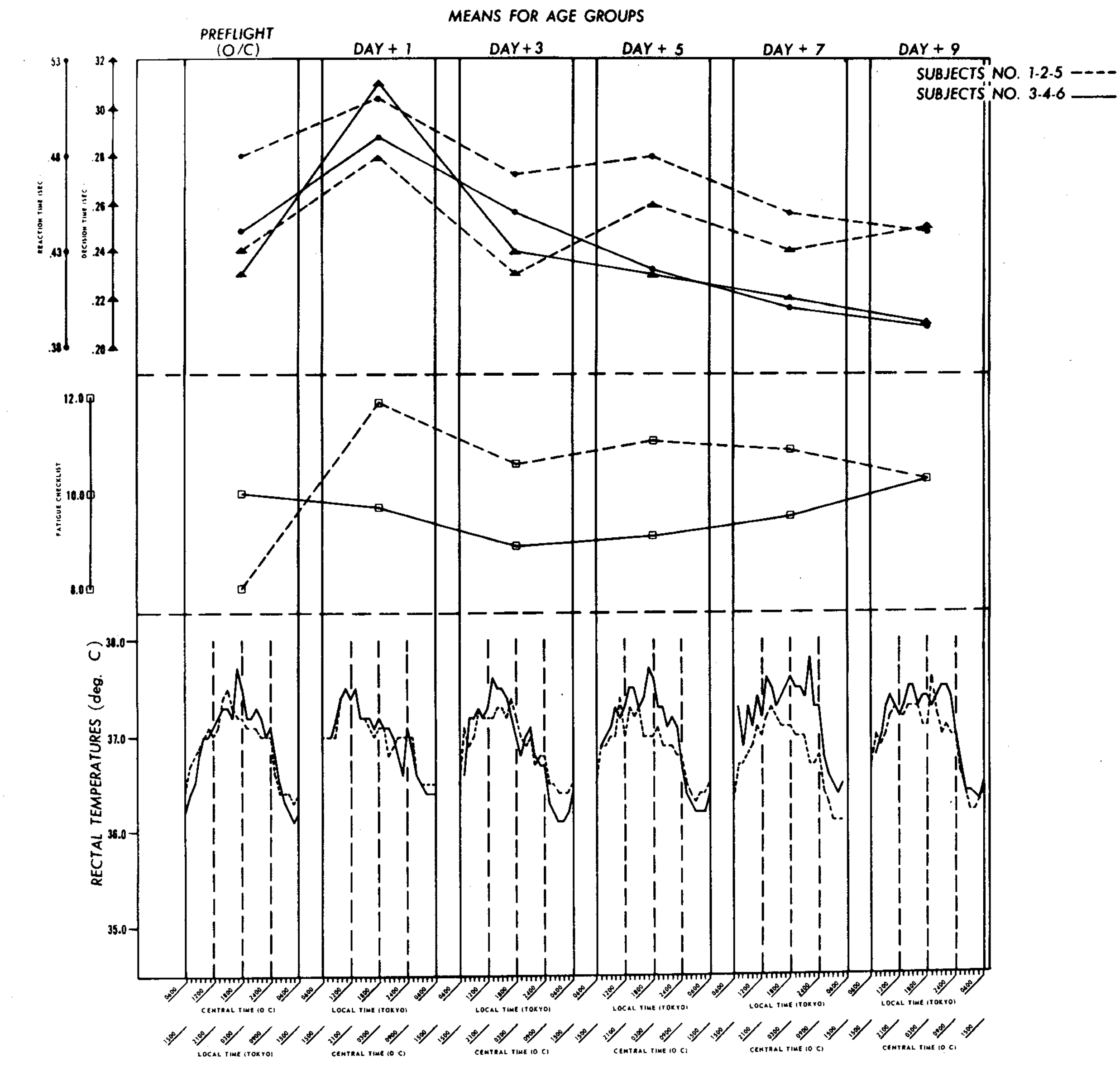

FIGURE 4. Comparison of mean values of rectal temperature, subjective fatigue, reaction time (solid circles), and decision time (solid triangles) based on the three older subjects (dashed lines) assessed prior to flight and following arrival in Tokyo with the mean values based on the three younger subjects (solid lines) assessed during the same periods.

1. As indicated by mean rectal temperatures, 3 to 5 days were required for the primary phase shift and 1 day for the back shift.

2. Interindividual differences in lag time were profound in that a completed phase shift was shown on the first day in Tokyo by one subject, while, at the other extreme, another subject did not demonstrate a normal phase shift on any of the days in Tokyo.

3. Behavioral integrity was degraded during the transitional period in Tokyo and, to a lesser extent, during the period of transition back to the environment or origin.

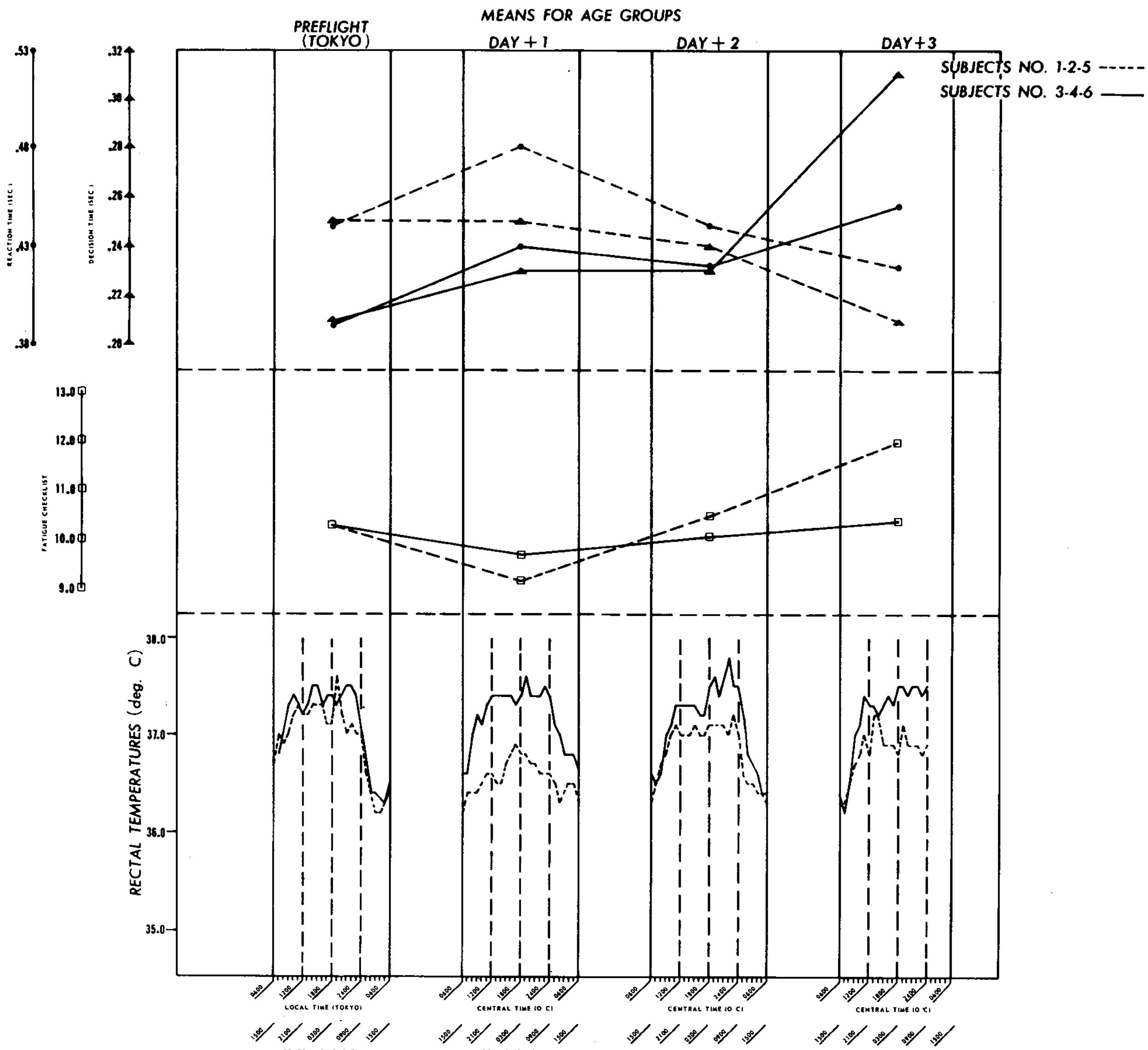

FIGURE 5. Comparison of mean values of rectal temperature, subjective fatigue, reaction time (solid circles), and decision time (solid triangles) based on the three older subjects (dashed lines) assessed prior to return flight and the following return to Oklahoma City with the mean values based on the three younger subjects (solid lines) assessed during the same periods.

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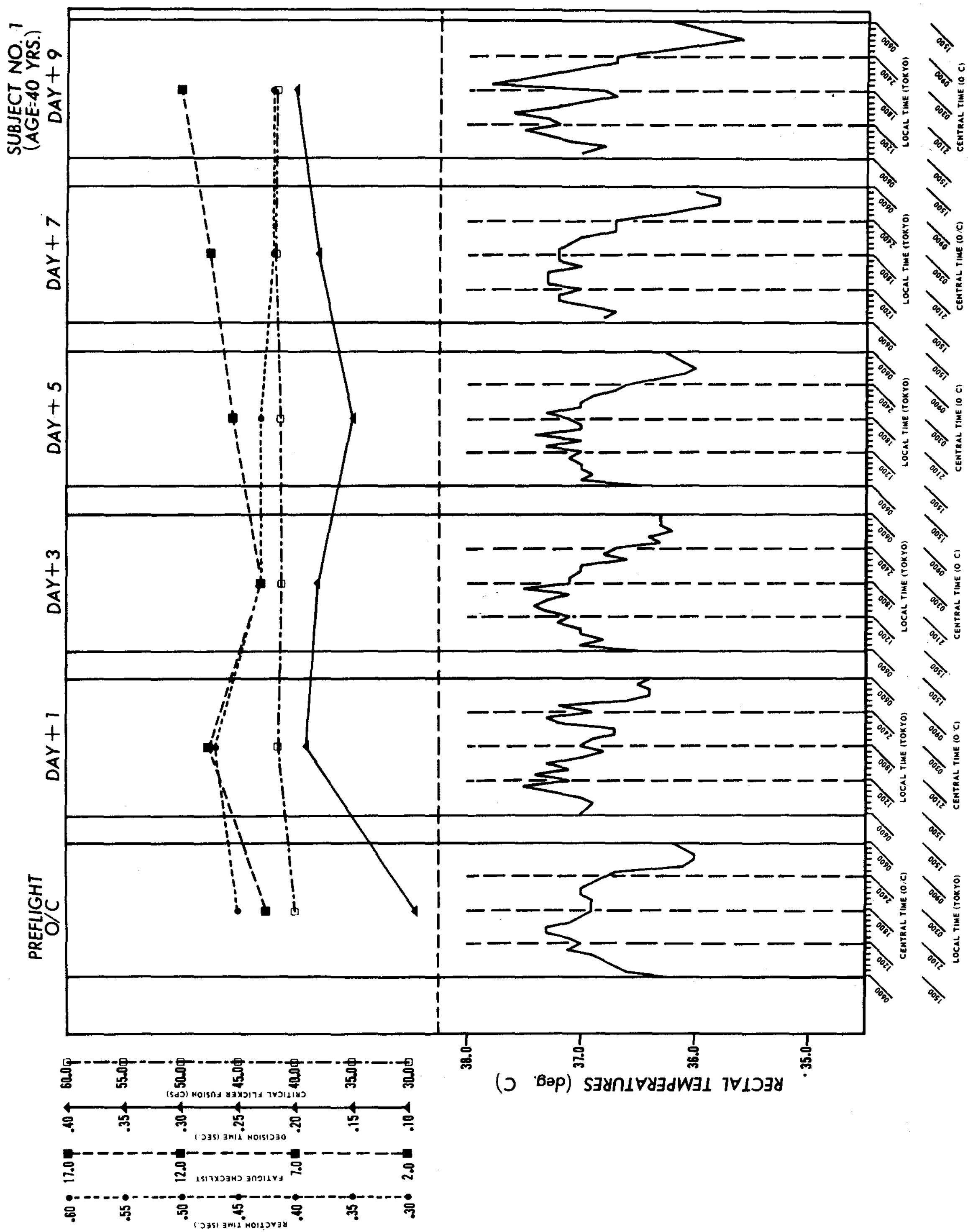

FIGURE A1. Values of rectal temperature, reaction time (time circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flickers-fusion obtained form Subject 1 assessed prior to flight and following arrival in Tokyo.

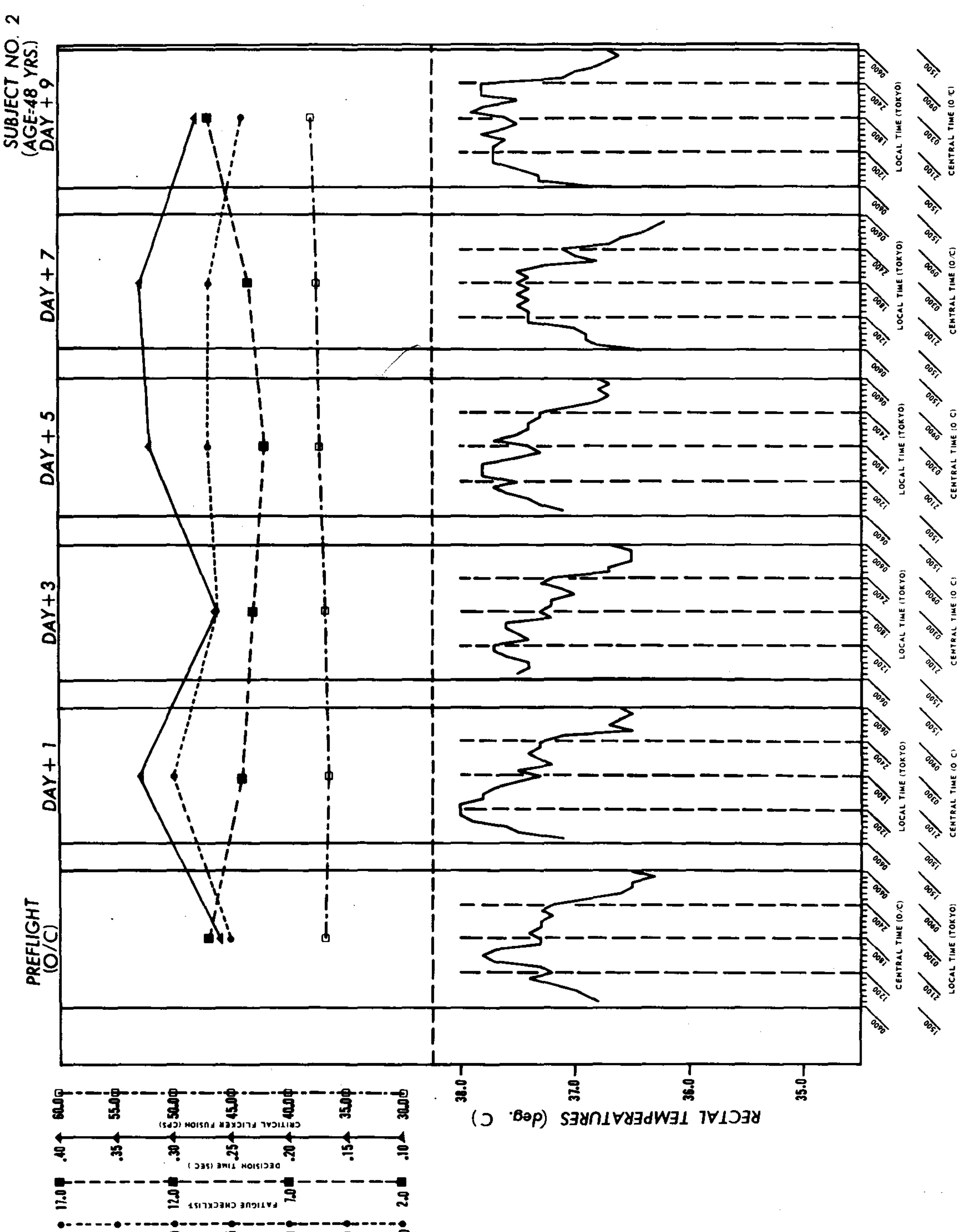

FIGURE A2. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 2 assessed prior to flight and following arrival in Tokyo.

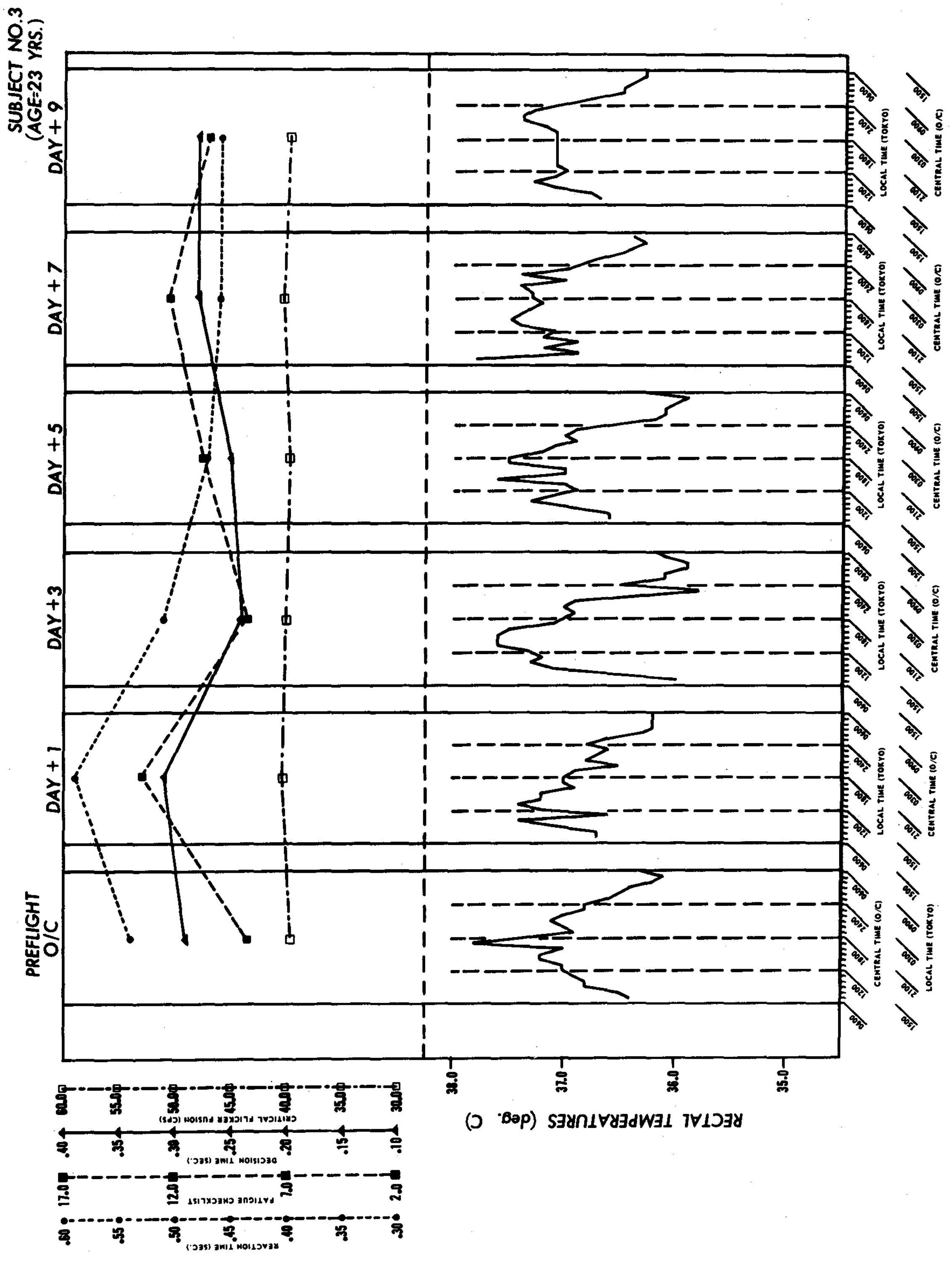

FIGURE A3. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 3 assessed prior to flight and following arrival in Tokyo.

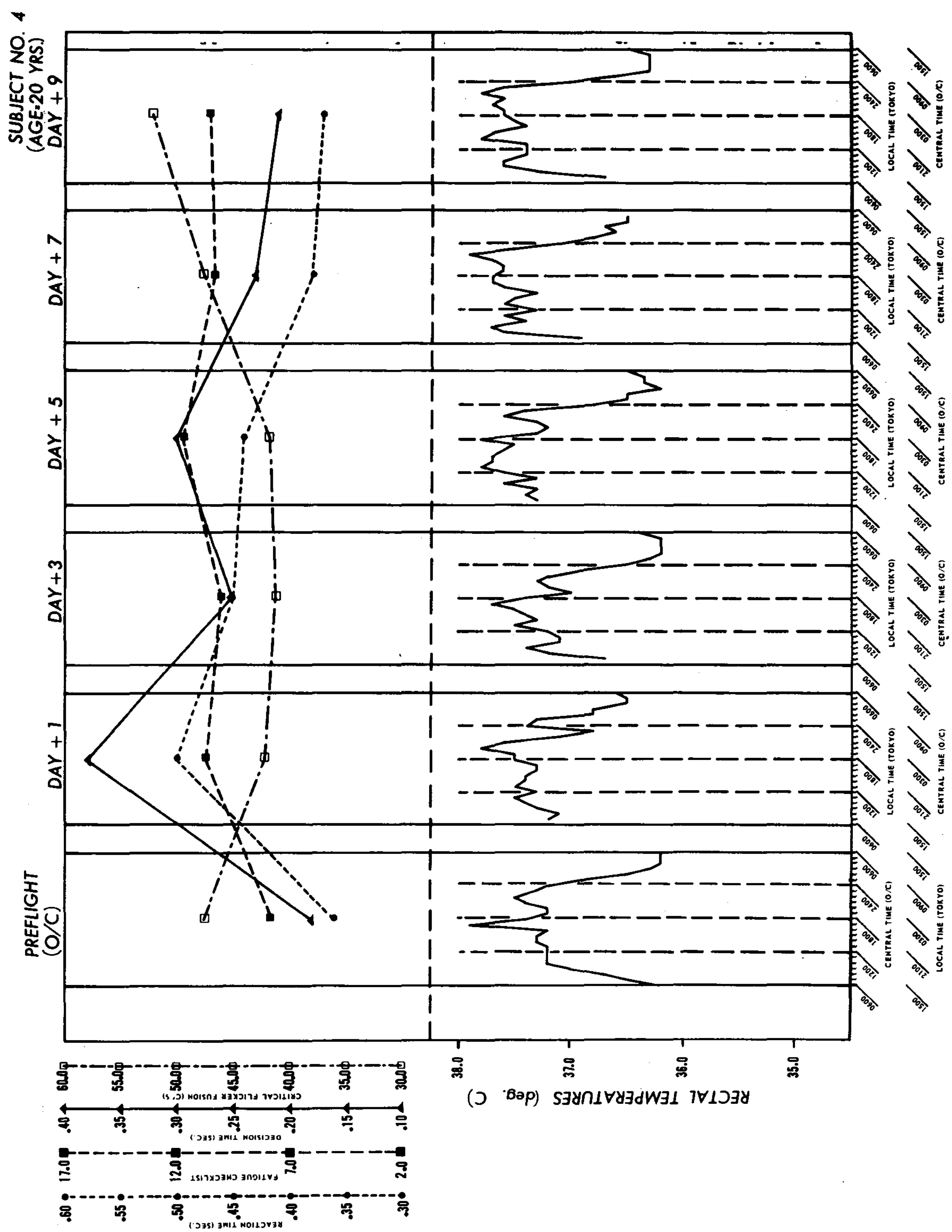

FIGURE A4. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares) decision time (solid triangles), and critical flicker-fusion obtained from Subject 4 assessed prior to flight and following arrival in Tokyo.

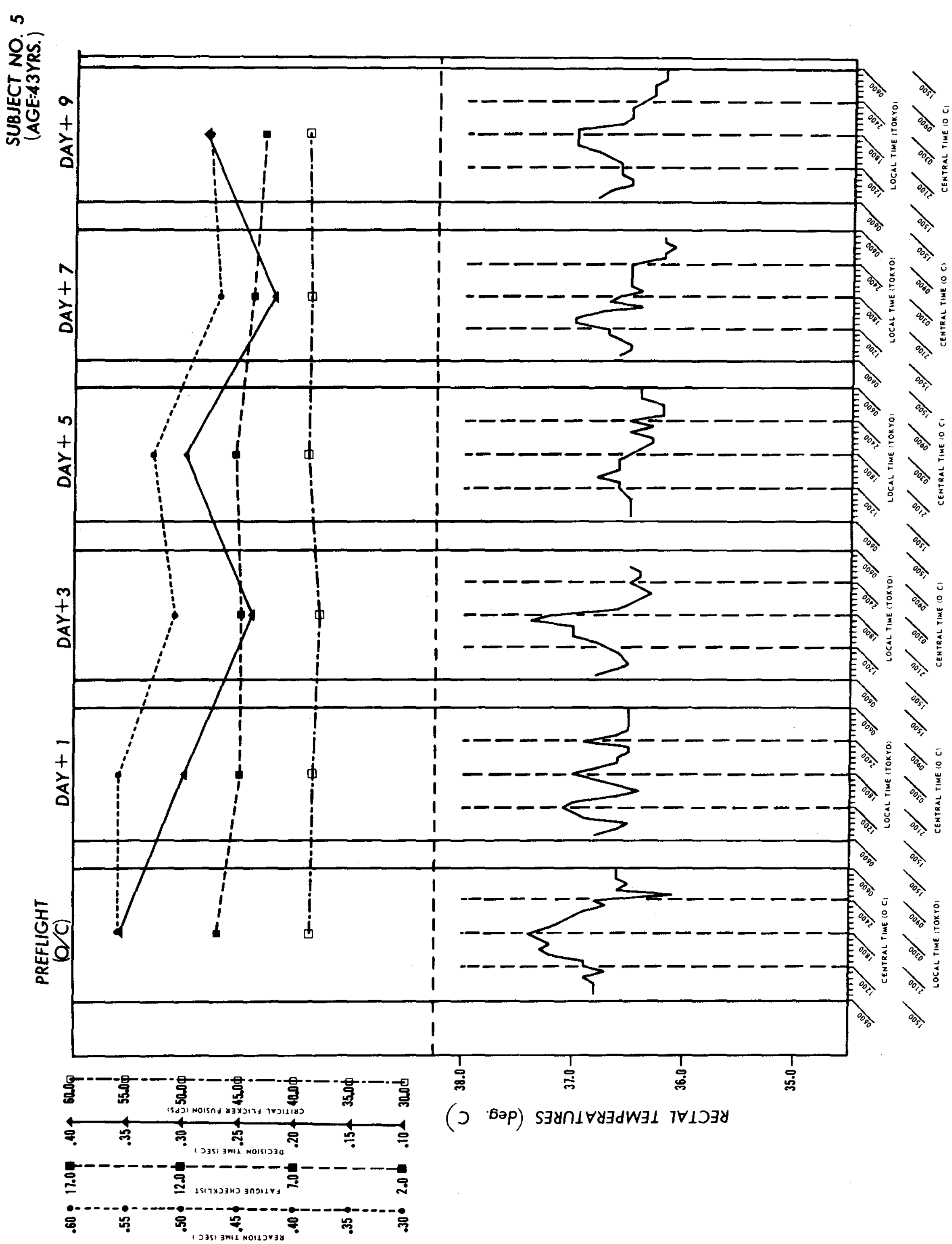

FIGURE A5. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and citical flicker-fusion obtained from Subject 5 assessed prior to flight and following arrival in Tokyo.

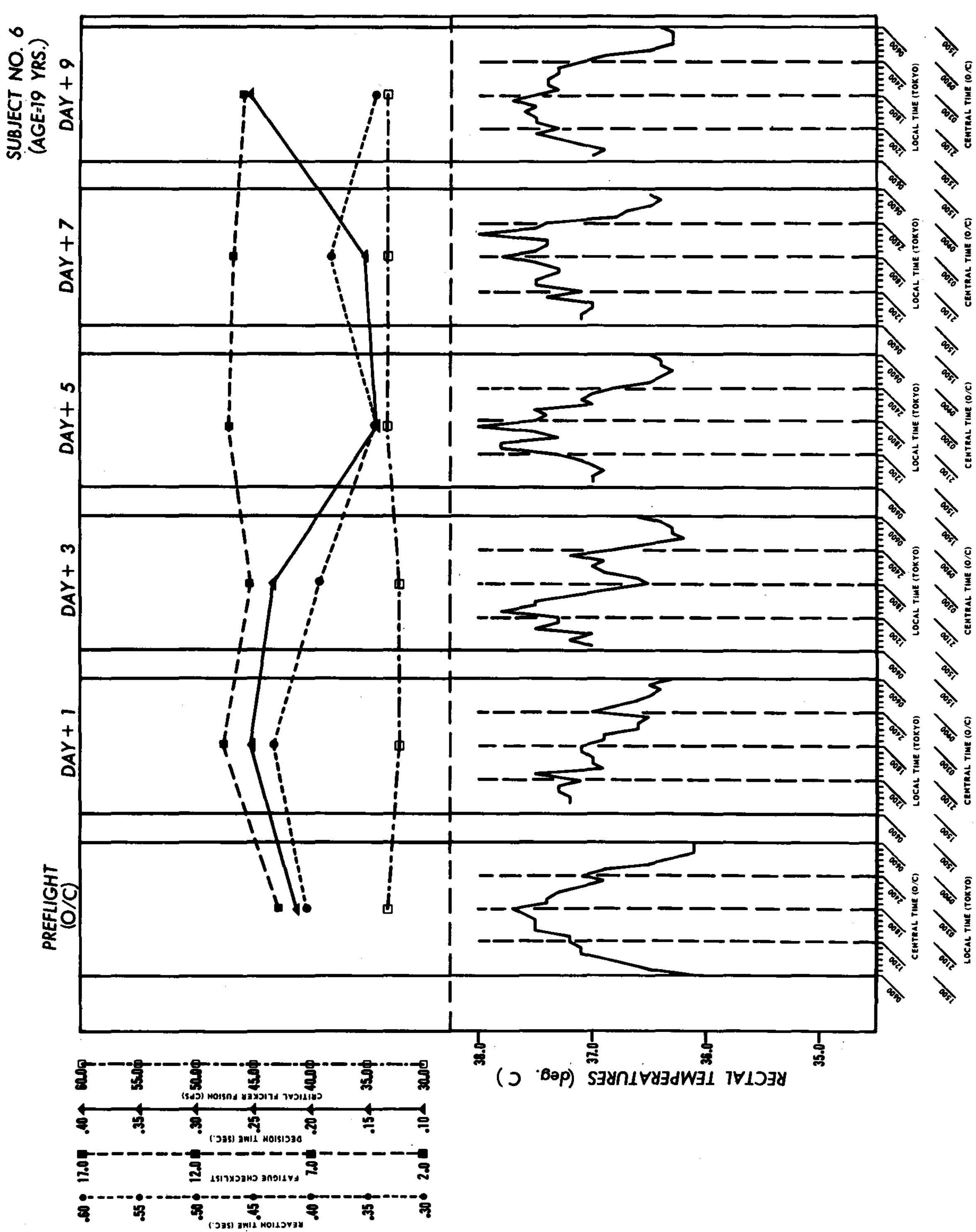

FIGURE A6. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 6 assessed prior to flight and following arrival in Tokyo.

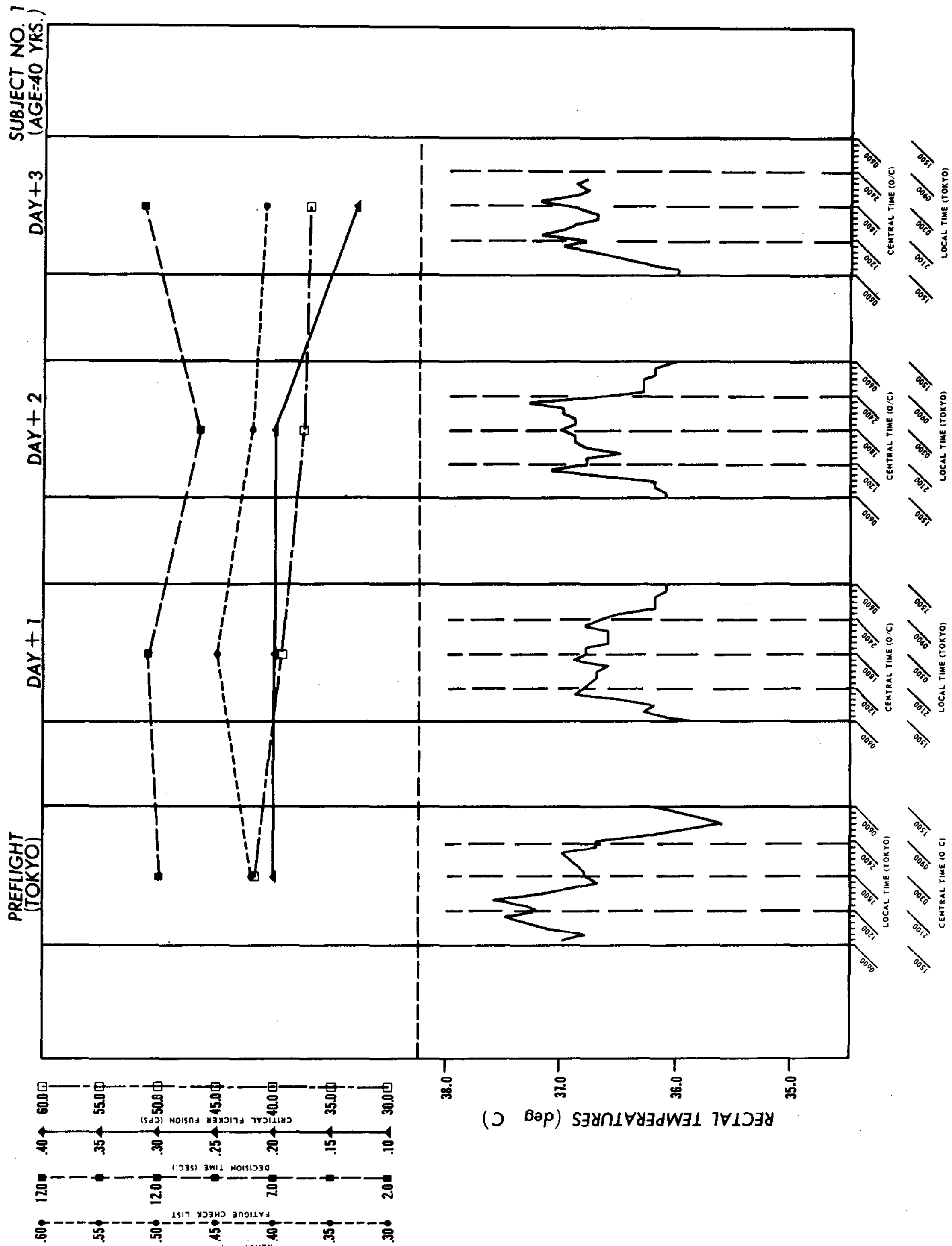

FIGURE A7. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 1 assessed prior to return flight and following return to Oklahoma City.

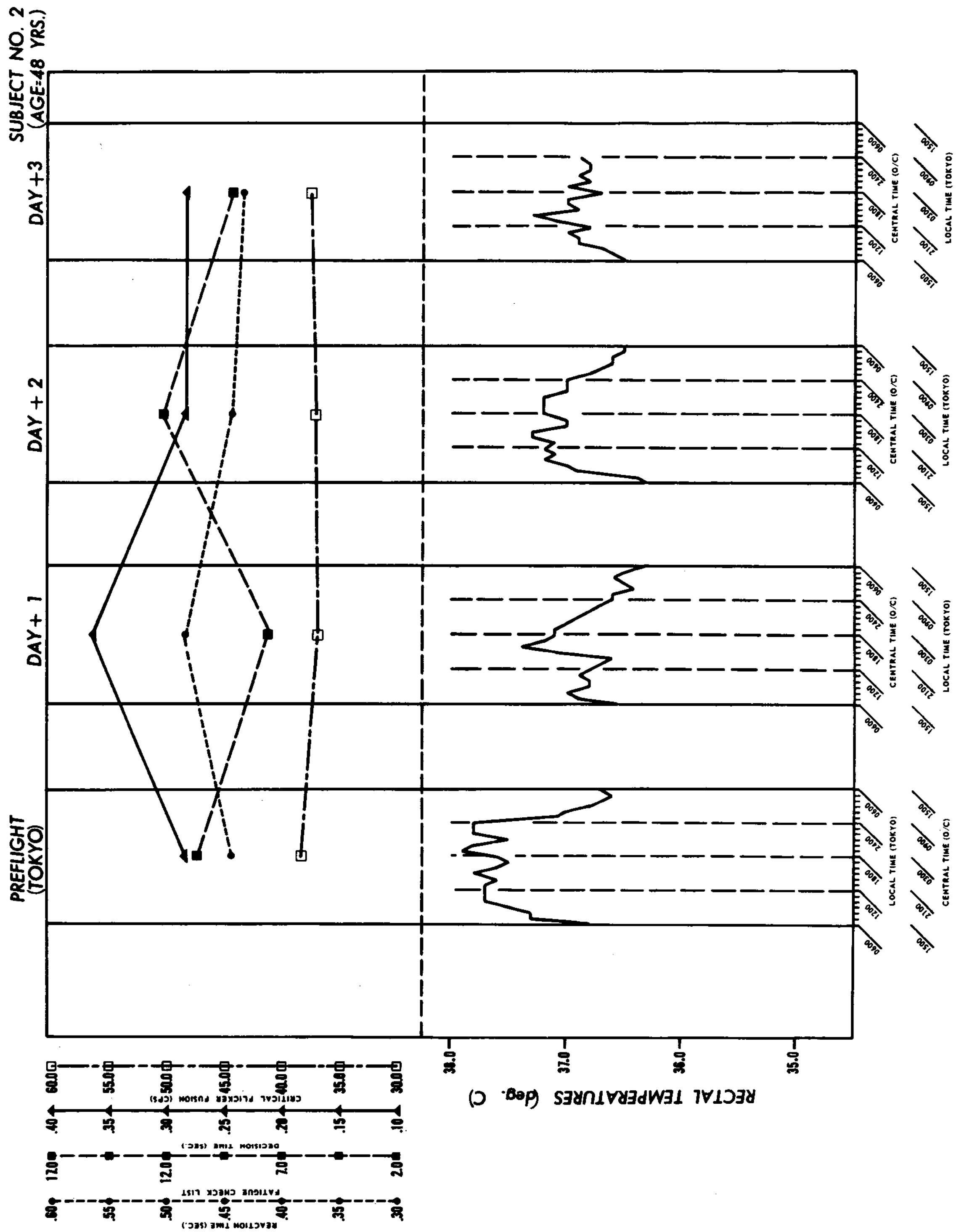

FIGURE A8. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 2 assessed prior to return flight and following return to Oklahoma City.

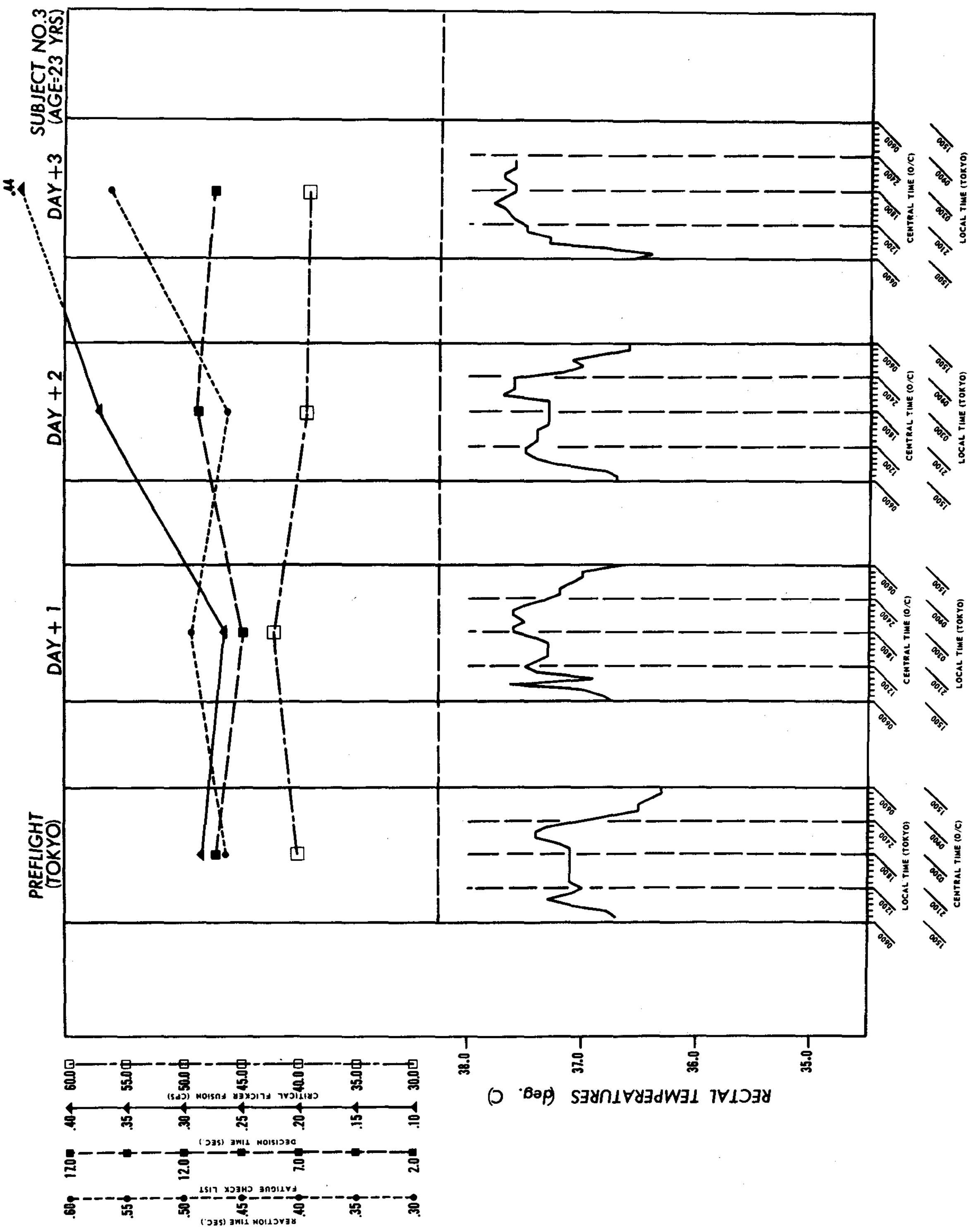

FIGURE A9. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 3 assessed prior to return flight and following return to Oklahoma City.

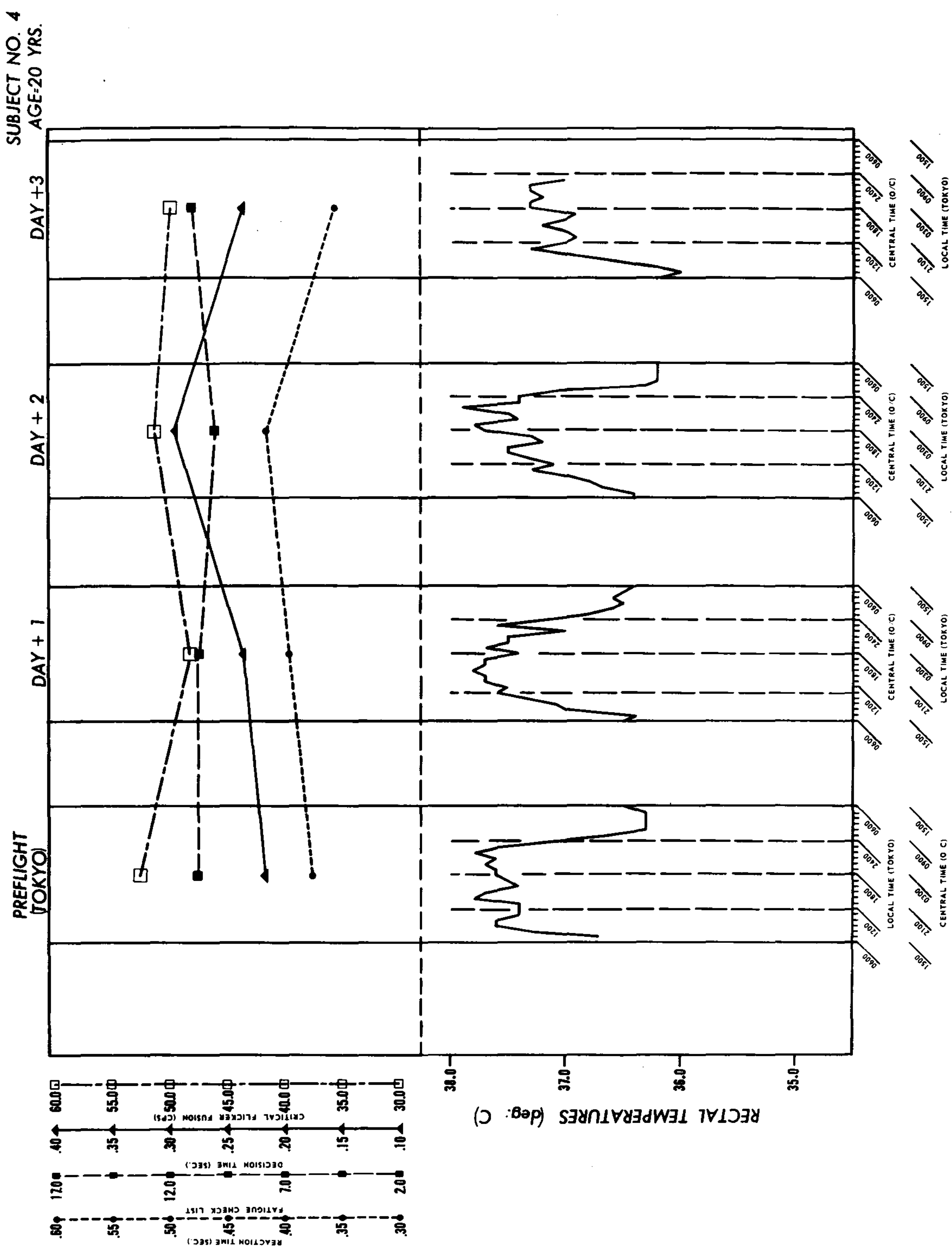

FIGURE A10. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 4 assessed prior to return flight and following return to Oklahoma City.

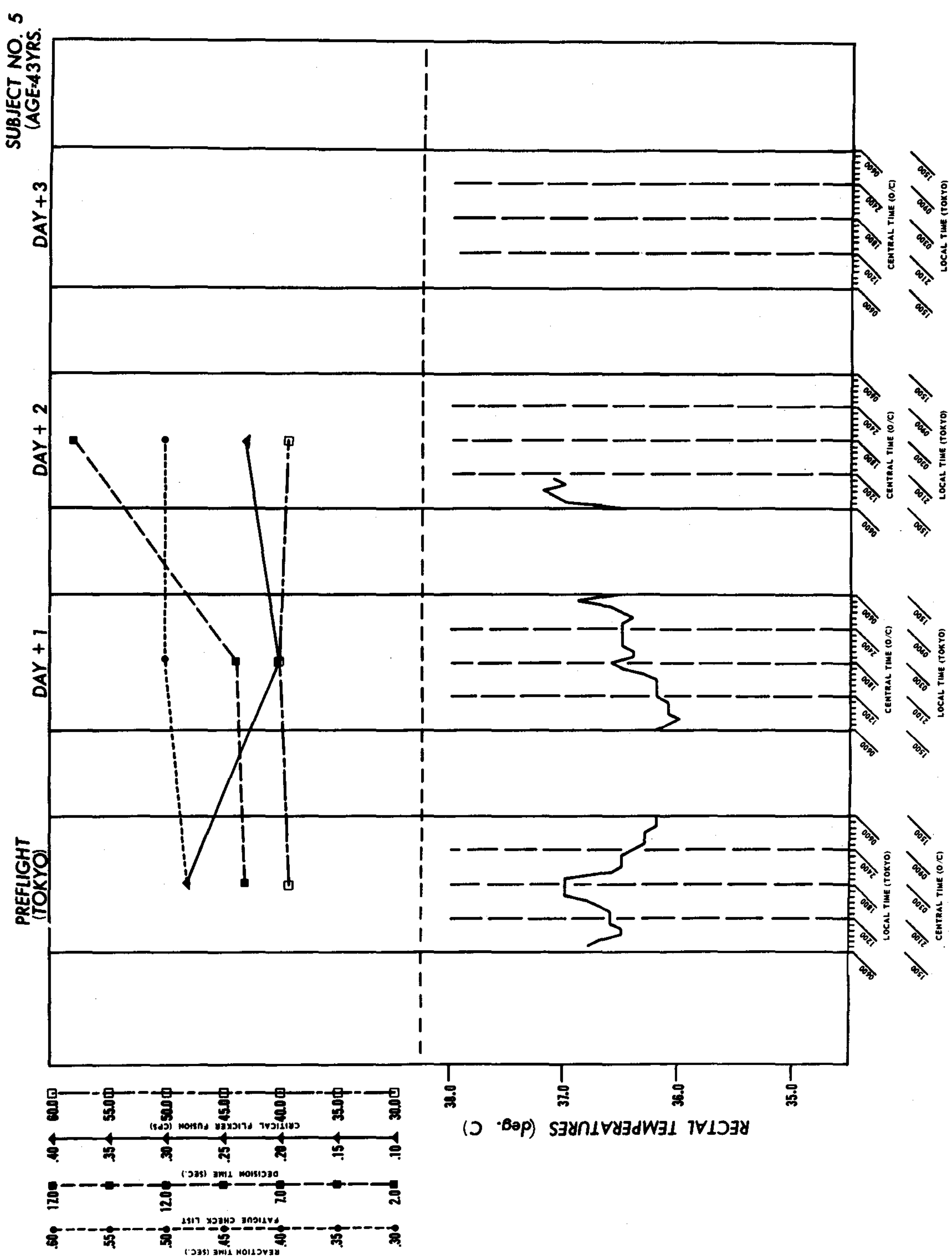

FIGURE A11. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 5 assessed prior to return flight and following return to Oklahoma City.

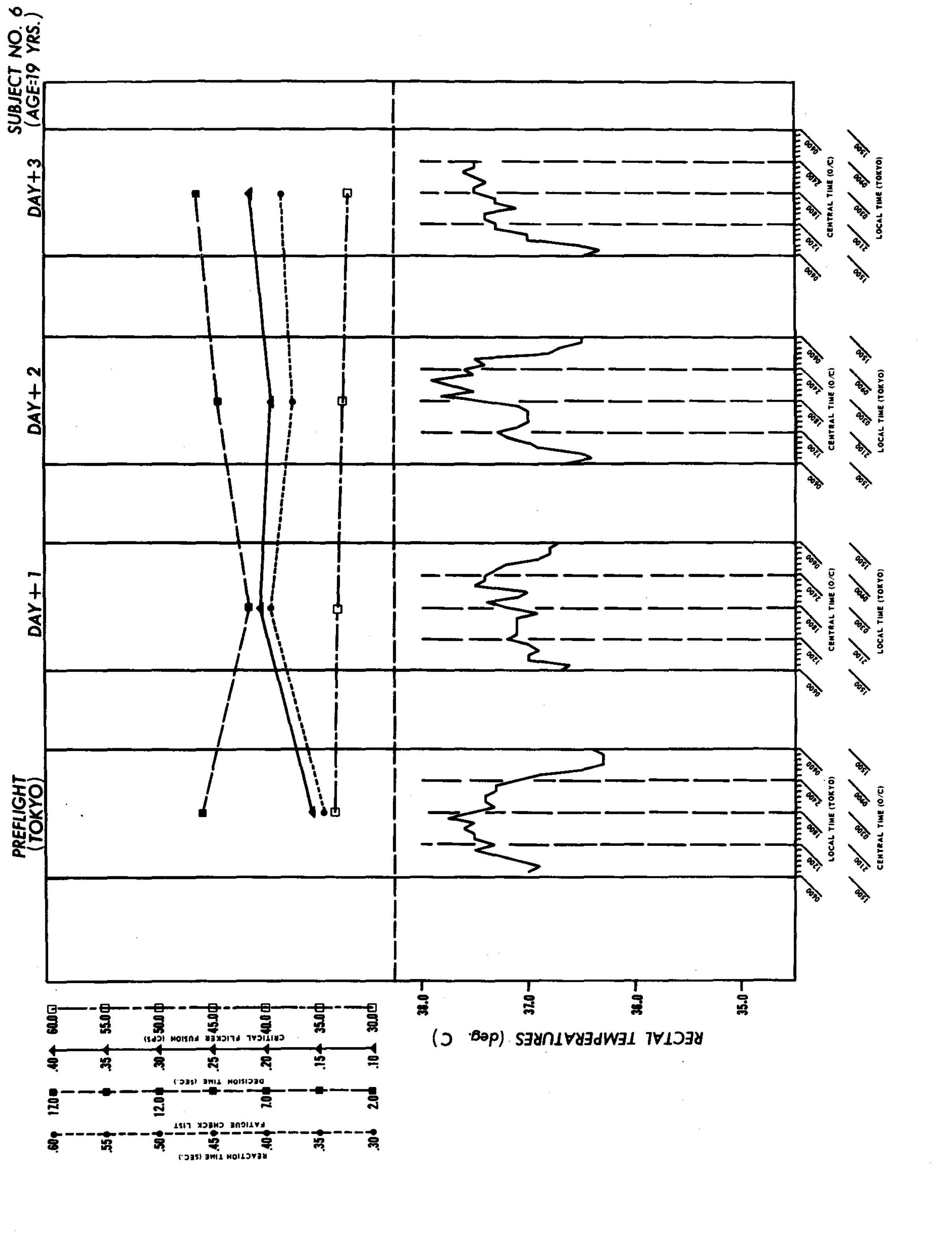

FIGURE A12. Values of rectal temperature, reaction time (solid circles), subjective fatigue (solid squares), decision time (solid triangles), and critical flicker-fusion obtained from Subject 6 assessed prior to return flight and following return to Oklahoma City.

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