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ADJUSTMENT OF THE DIURNAL RHYTHM IN BODY TEMPERATURE BY A TRANSPOSITION ACROSS THE LONGITUDES WITH A MODERATE SPEED

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ABSTRACT

Diurnal rhythm in body temperature and heart rate of 12 healthy athletes were recorded during a TransPacific voyage from Japan to the west coast of the United States. The speed of the ship was 14-16 knots which caused shortening of the actual length of a day by 32 minutes. The ratio of the lag of change in diurnal body temperature rhythm did not seem to be constant throughout the voyage. The adjustment of the rhythm to a new local time seemed to occur slowly during the first few days but fairly fast after the second week on the ship. During the voyage the rhythm was approximately 2 hours behind the typical temperature rhythm of the local time, and the rhythm could follow the new environmental routines in 3 or 4 days after arrival in USA. The results obtained suggest that the intrinsic biological rhythm formed during a longer period of time resists greatly distortion by a new environmental rhythm even with moderate speeds in trans-position.

The diurnal rhythm in body function appears to adapt fairly rapidly to new environmental routines, although there are some literatures showing that the rhythm is hardly disturbed by a displacement or an inversion of the daily routines of living[1)2)]. Sasaki[3)] reported that there was apparently no difference between the diurnal change in body temperature and the external periodicity of living with a slower transposition across the longitudes, but with a faster speed of transposition which resulted in change of a day by approximately 30 minutes one could see a disparity between the external periodicity and the diurnal rhythm. In this latter case, apparently three days seem to be necessary before the subjects' diurnal body rhythm is adjusted to the new environmental routine. Data observed for quickest transposition by a jet flight

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across the longitudes showed that 3-5 days were required for complete shifting of the rhythm[4]. These results suggest that the speed of cruise is not the most important factor influencing the speed of adaptation of body function to a new environmental routine. The mechanism of noticeable shifting of the temperature rhythm with a faster daily shift in routine of living of more than 30 minutes a day remains unclear. Although the answer for the reasons of the shifting will be given by an interaction of the "Zeitgaber" and the inner rhythm in body temperatnre change, relatively little experimental effort has been done. In this kind of investigation, there is need for either a large number of persons as subjects in order to neglect larger individual variations, or adequate protocol in checking the daily shifts of body function.

The authors had an opportunity to reexamine the experiments[3][5][6] on the shift of the rhythm in the 1965-1966, Nagoya university scientific and mountaineering expedition to the Andes. This paper describes the results and presents a few comments on the nature of the shifting of the daily rhythm in body temperature.

PROTOCOL

The subjects were 12 healthy members, 22-36 years old, of the 1965-1966, Nagoya university scientific and mountaineering expedition to the Andes. They left Yokohama on board Bolivia-maru, K-line, on October 11 th for Muroran, Hokkaido, and left Japan (141 °E) at midnight of October 14 th for Los Angeles, USA (118 °W), the first port of call. They arrived at Los Angeles on October 26 th, where they stayed for 3 whole days. They then left Los Angeles on October 29 th for South America (Fig. 1). The oral temperature and the heart rate were measured four times a day; 8 : 00 am, noon, 5 : 00 pm and 10 : 00 pm by local time from October 14 th November 13 th. Environmental temperature was kept nearly constant throughout the TransPacific voyage. Determinations of local time, latitude and longitude were supplied by the bridge officers.

RESULTS AND DISCUSSION

Mean oral temperatures are plotted by the Japan standard time (JAP ST time) (Fig. 2). The values did not differ much from the typical temperature rhythm in Japan (shown by the solid line in Fig. 2), but followed it closely during the first week after departure from Hokkaido. After the second week the values began to separate and shifted to the left from the typical temperature curve on the chart, so that it was difficult to get a precise regression line on the same chart. This shift of the temperature curve from the typical temperature rhythm in Japan can be more clearly observed in Fig. 3. The curve

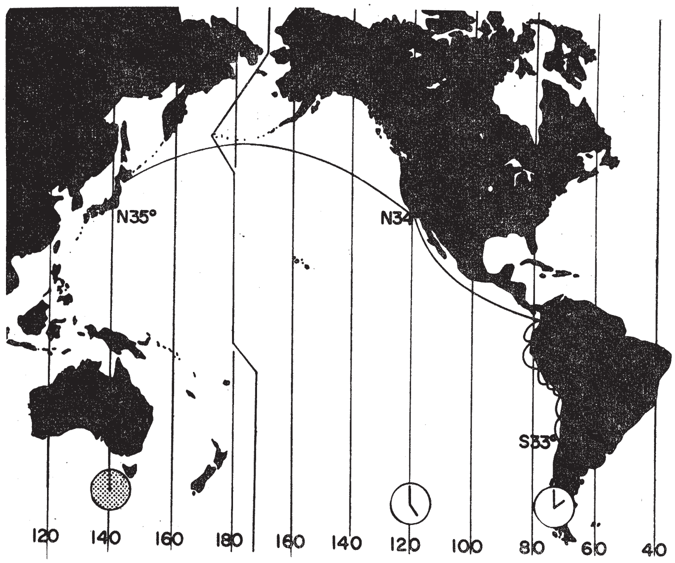

FIG. 1. Map showing TranPacific and South American route of the ship.

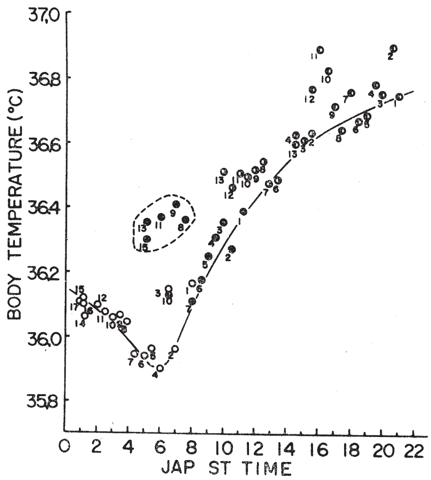

FIG. 2. Mean oral temperatures measured at 8:00 am (○), noon (●), 5:00 pm (◑) and 10:00 pm (◐) in local time during the transpacific voyage and in Los Angeles. The ordinate represents Japan standard time. Small numbers under each circle show the dates after departure from Japan. The solid line is an assumed body temperature curve of the subjects in Japan.

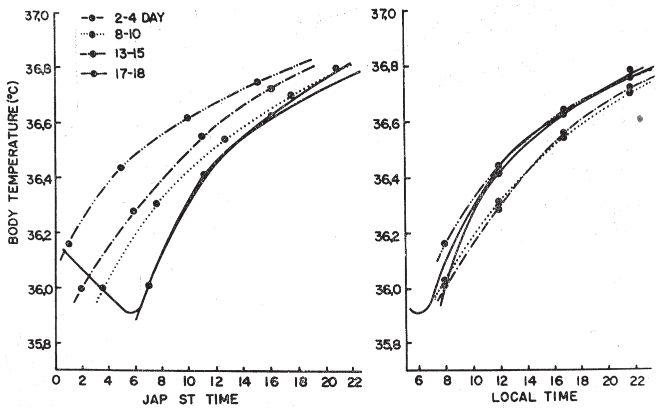

FIG. 3. Average temperature curves on 2-4 th (—●—), 8-10 th(· · · ● · · ·), 13-15 th(- · - ● - · -) and 17-18 th (- · · - ● - · · -) day after departure from Japan. The ship arrived in Los Angeles after 13 days transpacific voyage; therefore(- · - ● - · -) and (- · · - ● - · · -) represent 1-3 rd and 5-6 th day after arrival in Los Angeles respectively. Left: temperature curves represented on Japan standard time ordinate. The solid line is an assumed body temperature curve of the subjects in Japan. Right: temperature curves represented on local time ordinate. The assumed body temperature curve of the subjects in Japan is also represented on the same ordinate.

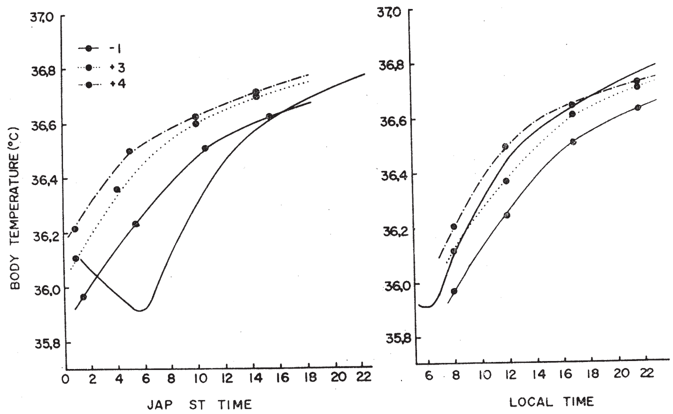

FIG. 4. Temperature curves of one day before (−1), 3 days (+3) and 4 days (+4) after arrival in Los Angeles, represented on the Japan standard time (left) and on local time (right).

for the 2-4 th day after departure from Japan was fairly close to the typical temperature curve in Japan, but those for the 8-10 th, 13-15 th and 17-18 th days shifted increasingly to the left in this order. When these temperature curves are plotted on the same ordinate for local time (Fig. 3 : right), a clear but different relation between the typical temperature curve in Japan and the average temperature curve during voyage can be observed. For the 2-4 th day after departure from Japan and for the 5-6 th day after arrival in Los Angeles (17-18 th day after departure), there was not observed definitely large difference between the two curves. However, the curves were approximately 2 hours behind the typical temperature curve for the 8-10 th day after departure from Japan and 1-3 rd day after arrival in Los Angeles. Fig. 4 shows the relation of the typical temperature rhythm in Japan and the temperature curve 1 day before the subjects arrived in USA and 3 and 4 days after they arrived in Los Angeles. The curves plotted on local time suggest that the temperature rhythm could follow the new environmental routine in 3 or 4 days after arrival in Los Angeles.

According to Sasaki[3] the mode of adjustment of diurnal temperature rhythm to a new local time can be classified into three groups, and the difference of the mode accounted for by a difference in the speed of transposition across the longitudes. With a slow speed of transposition in which the change of actual length of a day is less than 25 minutes, the change in local time and the change in diurnal body temperature rhythm coincided well and no time lag was seen between the two[5)7)8)]. With a faster speed of transposition where the change of actual length of a day is 32 minutes the diurnal rhythm could not follow the day-to-day change of local time. By faster transposition the lag of change in temperature rhythm from that of local time is assumed to be increase in proportion in the days lapsed in transposition, as the daily, small but constant, lags in temperature rhythm will be accumulated during the voyage.

To show the relation between these changes, Sasaki[3] has drawn a clear figure (his method was applied to the data obtained in this investigation, Fig. 5). If the assumption mentioned above is right, the lines of local time change and the temperature rhythm can be drawn without many measurands during voyage on the days required in transposition and shift in local time relationship. By studying the results shown in the three figures (Figs. 2-4), the middle figure in Fig. 5 (− 32 NUSEA) may be drawn as being the most reasonable one representing the relationship between the change in local time and that of temperature rhythm, in this investigation. The ratio of the lag of change in diurnal body temperature rhythm does not seem to be constant throughout the voyage. Adjustment of the diurnal rhythm to a new local time seemed to occur slowly during the first few days, but seemed to take place fairly fast after the 4-5 th day. In this point the result differs from that reported by Sasaki.

The importance of the morning rise in body temperature has been empha-

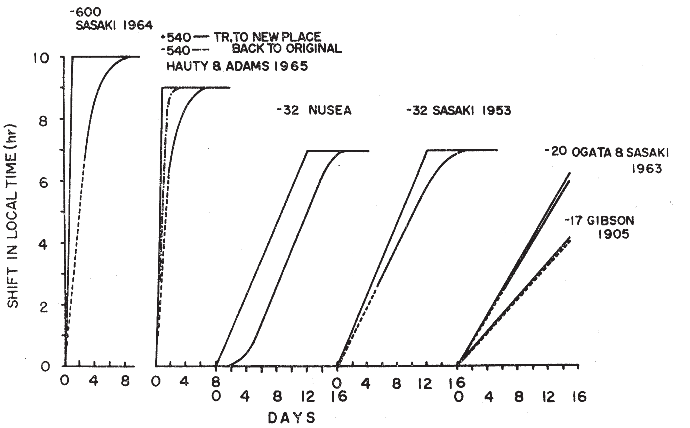

FIG. 5. Schematic representations of adjustment of diurnal body temperature rhythm to a new local time at different speeds of transposition. Shifts in local time are represented by solid straight lines. Shifts in body temperature rhythm are shown in combination of solid and broken curves. Inserted numbers: showing the changes of actual length of a day in minutes. +: westbound transposition, −: eastbound transposition. NUSEA: the result in this investigation and the relation is exaggerated to help understanding. The first day after departure is expressed as 0 day on the figure.

sized by Ogata and Sasaki[5] in studying the phase shift of the diurnal rhythm. A persevering and continuous effort in recording the temperature, however, will be required to check the morning rise, but such did not seem to be so practical in investigations with the members of the expedition. Without checking the morning rise, the phase shift in the rhythm can be also clearly observed by using a sufficient number of subjects, without too many measurements in a day.

The results obtained with the fastest transposition, as by a jet aircraft, showed that a greater amount of time lag will be left and the relation of the local time change and the rhythmic change does not seem to be simple[3]. During the first few days the adjustment to a new local time occurs very slowly but later proceeds rapidly, so that the curve of the temperature rhythm could assume the S-type. This mode of the shift in body temperature rhythm resembles more that obtained in this investigation and shows that the internal rhythm will have some resistance to be triggered to move for the adjustment and when the mechanism is once triggered, it will follow well the change of local time. Hauty and Adams[4] reported an important and interesting result on the phase shift of the temperature change and in which in primary shift across the longitudes the time required for adjustment to new environmental routines was much longer than that required for readjustment to the original routines. With such investigations the results obtained in this investigation suggest that the intrinsic biological rhythm formed during a longer period time resists greatly distortion by a new external rhythm.

A change in diurnal body rhythm was also observed by measuring the heart rate during the voyage, but the results were more scattered than those of body temperature change.

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REFEPENCES

1) Mills, J. N., Diurnal rhythm in urine flow. *J. Physiol.*, **113**, 528, 1951.
2) Toulouse, E. and Piéron, H., Le mécanisme de l'inversion, chez l'homme, du rhythme nyctheméral de la température. *J. Physiol.* (Paris), **9**, 425, 1907; Cited by Mills, J. N., Human circadian rhythms, *Physiol. Rev.*, **46**, 128, 1966.
3) Sasaki, T., Effect of rapid transposition around the earth on diurnal variation in body temperature, *Proc. Soc. Exptl. Biol. Med.*, **115**, 1129, 1964.
4) Hauty, G. T. and Adams, T., Phase shifting of the human circadian system. In: *Circadian clocks*, edited by J. Aschoff. North-Holland Pub. Co. Amsterdam. p. 413, 1965.
5) Ogata, K. and Sasaki, T., On the causes of diurnal body temperature rhythm in man, with reference to observations during voyage, *Jap. J. Physiol.*, **13**, 84, 1963.
6) Sasaki, T., Some experiments on the mechanism of the diurnal variation in the human body temperature, with particular reference to some influence of labyrinth, *Bull. Res. Inst. Diath. Med.*, **3**, 262, 1953 (in Japanese).
7) Gibson, R. B., The effects of transposition of the daily routine on thc rhythm of temperature variation, *Amer. J. Med. Sci.*, **129**, 1048, 1905.
8) Osborne, W. A., Body temperature and periodicity, *J. Physiol.*, **36**, Proc. 39, 1908.