Entrainment and the primate circadian rhythm¹

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The existence of a 23-hr periodicity in the free-running Nemestrina circadian rhythm is confirmed. This rhythm exerts considerable influence on simple entrained operant behavior.

The study of circadian processes has, for the most part, been an end in and of itself, with various researchers attempting to specify phase relations, periodicity, and external and internal determinants of both the entrained and free-running processes (Harker, 1964). While this approach has been biologically most elucidating, its obvious extension and correlation with overt behavior has, with the possible exception of gross activity, received little attention. A possible explanation of this sparsity is the extensive utilization of invertebrate species and the lack of suitable analytic techniques capable of discerning changes in the waking behavior of these organisms. However, recent demonstrations of a circadian process in the primate during extended periods of isolation (Ternes & Farrer, 1966; LeVere, 1967) provide both the S and techniques required to relate endogenous rhythms to various overt behaviors. The present study has thus attempted to relate the performance of a simple operant schedule of reinforcement to two separate physiological indicants of the primate circadian rhythm.

Subject

The S for this study was an adult male *Nemestrina* monkey from the colony maintained at the Edsel B. Ford Institute for Medical Research.

Apparatus

The apparatus (acoustical cubicle and inner monkey compartment) and maintenance equipment previously described by LeVere (1967) were replicated for the current procedures except for the removal of the ad lib conveyor belt and the addition of two 1-3/8 in. diameter stimulus lights on the response panel. With S restrained in a primate chair, these lights were located on a horizontal line about eye level, 3 in. above and 6 in. to either side of the center of a response lever located directly in front of S. As with the previous arrangement, lighting was again provided within the monkey chamber by two 100-W, 115-V bulbs wired in series and located approximately 1-1/2 ft above S's head, while extraneous sounds were masked by continuous random noise set at 75 dB (re .0002 dyne per cm²).

The temperature within the monkey chamber, recorded at approximately 0830 h daily, remained between 65° and 81°F during the entire isolation period with a mean difference between successive days' observations of 1.73°F.

Procedure

Prior to the 90-day isolation, pulse leads (right and

left abdominal) and a temperature probe (left abdominal) were implanted under aseptic conditions. These leads were respectively connected to a Grass electroencephalograph and a Rustak recorder, and the physiological processes automatically monitored for 30 sec every half hour.

Each of the 90 "days" (extending from 1200 to 1159 h) was divided into four work periods respectively commencing at 1200, 1800, 2400, and 0600 h. Each work period was of a maximum duration of 1 h and was signaled by illumination of the stimulus light above the food receptacle located below the response panel to the animal's right, while the intervening rest periods were indicated by the illumination of the opposite stimulus light. During each work period when the S^D was illuminated, the animal had the opportunity to obtain 10 monkey chow pellets by pressing the response lever in accord with a Fixed Ratio (FR) schedule initially set at FR 5 but subsequently increased to FR20 (Day 4), FR 30 (Day 5), FR 50 (Day 12), FR 75 (Day 18), and finally FR 100 (Day 30), where it remained. The 40 pellet per day ration was determined from the ad lib intake of a similar animal under identical conditions of isolation (LeVere, 1967).

Results

Over the entire 90-day isolation period the animal earned an average of 38.8 pellets per day. This represents a mean difference of 1.2 pellets per day from the total possible 40 pellets and indicates that the S was, on the whole, responding for all available food during each work period.

The major findings are presented in the four matrices shown in Figs. 1 through 4. All matrices are organized on identical formats which present the entire 90-day period as 4320 individual 1/2-h cells. The physiological

Fig. 1. Darkened cells indicate 1/2-hr periods where pulse rate was in upper quartile range for a particular day.

Fig. 2. Darkened cells indicate $\frac{1}{2}$ -hr periods where temperature value was in upper quartile range for a particular day.

measures presented in Figs. 1 and 2, respectively, indicate by darkened cells the daily upper quartile pulse rates and temperature values. The response data are similarly presented in Figs. 3 and 4 with the former indicating the occurrence of one or more responses by a darkened cell. Figure 4 shows a measure of "Ratio-Efficiency" by indicating with bars the 6-h period within a given day which enveloped the work period where the mean time to obtain a single reinforcement was lowest, i.e., total time spent responding divided by number of rewards earned. The figures thus present two physiological indices of the circadian process and, additionally, how these are reflected in the animal's overt bar-press behavior.

Discussion

As indicated in the presented figures, the results confirm the existence of a 23-h periodicity in the free-run-

Fig. 3. Darkened cells represent the occurrence of one or more responses within the indicated $\frac{1}{2}$ -hr period.

Fig. 4. Bars represent 6-hr periods surrounding the work sessions with highest "Ratio-Efficiency" as measured by mean time between reinforcements.

ning Nemestrina circadian rhythm (LeVere, 1967) and additionally suggest temperature as one of the primary indicants of this process. Further, it is most important to note that this 23-h period was maintained even though the animal was required, and did, obtain the allowed portion of its daily food ration during the four equally separated 1-h work sessions. These results would then appear to indicate possible dissociation between entrained activity and an organism's rhythmic physiological processes.

However, that this dissociation is at best incomplete is indicated by the patterning of anticipatory responding (Fig. 3) and the best daily work sessions as measured by shortest average time between reinforcements (Fig. 4). The correspondence of these measures to the physiological indicants demonstrates that not only does the underlying circadian process exert a strong bias over the occurrence of activity but also, and more importantly, it determines the manner in which the organism performs the activity independent of "entrainment." Thus, while circadian processes are undisputably credited with a pivotal position in the determination of the "when" of behavior, the present results further extend their influence to the "how" of behavior.

References

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Note

1. The author wishes to acknowledge the support of grant NASr-83 from the National Aeronautic and Space Administration.