Feeding time entrainment of activity and self-produced illumination change in a squirrel monkey*

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Daily feeding time was changed or left the same for four 20-day replications (A, B, B, C) for one female squirrel monkey while quantifying tilt cage activity and number of illumination changes/hour. Periodic regression analysis indicated that a statistically significant circadian cycle (23.5-24.6 h) was present for each replication. In addition, significant Phase by Replication interactions verified that feeding time served as an effective entraining stimulus for the two dependent variables under investigation.

Of the variety of stimuli which organisms of all species contact daily, periodic fluctuations of illumination intensity appear most crucial for the entrainment, or synchronization of circadian cycles (Aschoff, 1965). However, there is some evidence that in the absence of fixed light cycles, temperature cycles (Hoffman, 1963; Swede, 1963; cited in Aschoff, 1965) and noise (Aschoff, 1965) may act to entrain such day length cycles. Enright (1965) argues that, since most organisms produce behavioral and physiological rhythms with period lengths which differ consistently from 24 h when maintained under constant, rather than cyclic illumination, laboratory noises and feeding regimes cannot exert a *major* (italic his) synchronizing, or entraining, effect.

The present investigation of feeding time entrainment was conducted as a result of the adventitious observation that an isolated female squirrel monkey who was self-selecting illumination (both duration and intensity at all times of day) was consistently displaying both an illumination and cage activity cycle which, while approximately 24-h long, was clearly nocturnal and apparently was temporally correlated with her feeding schedule.

METHOD

Subjects

The S was one female *Saimiri sciureus* about 4 years old at the start of the experiment. Until 14 weeks prior to the start of the experiment she had been maintained on a 12-h cycle of alternating light and dark (lights on: 0600-1800 h, DST) and had been fed twice daily (0900 and 1600, DST). At this time feeding was limited to 1600 h, and illumination level (0-25 fc) selection was permitted from 1000-1200 h and from 2200-2400 h daily for 6 weeks. For the last 8 weeks before the experiment began, illumination manipulation was possible 24 h/day. Feeding time remained at 1600 h.

Apparatus

The test enclosure was a 64 x 46 x 40.5 cm tilt cage with grid floor and frosted Plexiglas top. The spout for the fluid reservoir was located 32 cm from each end, over the fulcrum of the tilt cage, and 10 cm from the grid floor. A 10 x 8 cm opening on the opposite wall permitted hand delivery of the daily food ration to a 10.5 x 8 x 7.5 cm wire-mesh food hopper. A hinged metal plate kept this opening securely closed except at the feeding time.

The interior of the test enclosure was painted flat black except for the grid floor, Plexiglas top, and a white 15-cm-diam disk with a 2-cm handle, which was centered laterally and 20 cm above the grid floor on one end of the box. This disk, which served as a manipulandum, could be rotated through an arc of 180 deg (270-90 deg) to operate six positions of a silent rotary switch. The switch operated five incandescent lamps in a "chandelier", placed 66 cm above the top through relay programming equipment located in a control room. The test enclosure was housed in a 2.12 x 1.59 x 2.46 m ventilated concrete block room in which the noise level was 80 dB SPL. When lights from the "chandelier" were off, no light from doors' edges or vents could be detected by two independent dark-adapted humans, nor could noises from the laboratory be heard over the masking noise.

The lights from the "chandelier" initially were programmed to produce dark, .5, 1, 2, 6, and 25 fc with each successive 30 deg turn of the disk manipulandum. Two months before the beginning of this experiment, the sequence was randomized to 1, 6, 0, 25, .5, and 2 fc for each 30 deg increment from 270 deg to 90 deg. This sequence was used throughout the present study.

Cage activity and number of illumination changes were recorded in 15-min increments on a printout counter. Duration under each self-selected level of illumination was recorded nearby on electromechanical counters.

Procedure

Feeding time and general maintenance time were conducted at 1600 h for 20 days (Replication A), at 2400 h for two 20-day blocks (Replication B_1 and B_2), and at 0730 h for a final 20-days (Replication C). The second 20-day block (B_2) at 2400 h was conducted as a control for the possibility that the obtained results were attributable to a systematic phase shift unrelated to feeding and maintenance time. The experiment was terminated after the 0730-h feeding time replication due to a prolonged power failure which prevented data collection for 9 days and during which time the monkey was returned to the colony room.

Table 1
Degrees of Freedom (df), F Ratios (F), and Associated Probability Values (P) from the Periodic Regression
Analysis of Cage Activity Scores for Replications A, B₁, and C

Source	df	Replication A		Replication B₁		Replication C	
		F	P	F	P	F	P
24-h Period	2/378	54.94	< 0001	54.43	< .0001	168.66	< .0001
Scatter	21/378	.94		.94		6.36	< .0001
Days by Amplitude	18/378	3.37	< .001	3.73	< .001	6.68	< .0001
Days by Phase	18/378	2.48	< .01	1.50	> .05	3.37	< .005
12-h Period	2/342	–		–		66.76	< .001
Scatter	19/342	–		–		1.64	> .05
Days by Amplitude	18/342	–		–		3.44	< .001
Cycle Length		24.10		24.03		23.50	

RESULTS

Hourly cage activity and illumination change scores were analyzed using a periodic regression analysis proposed by Bliss (1970, p. 223ff)[1]. Table 1 presents cycle length and ANOVA on activity measures of Replications A, B₁, and C of the study. Phase B₂, a replication of Phase B₁, produced essentially similar results and, therefore, is not included. Table 2 presents ANOVA and cycle length findings for the illumination change measures for the same experimental phases.

Additional periodic regression analyses were conducted to examine phase and amplitude shifts from one experimental condition to the next. The activity peak shift from Replication A to B₁ of 3.83 h was found to be significant. The Replication by Phase Interaction was significant ($F = 30.28$, $df = 1/21$, $p < .01$). The illumination change peak shift from Replication A to Replication B₁ of 5.38 h was also significant ($F = 8.51$, $df = 2/21$, $p < .01$). However, the illumination change peak shift from Replication B₂ to Replication C, while large (7.74 h) was not significant ($F = 2.50$, $df = 1/21$, $p > .10$), a finding largely attributable to the increased scatter associated with Replication C illumination measures.

Figures 1 and 2 present the best fitting curves for Replications A, B₁, and C for the two dependent variables. The letters A, B, and C above the abscissa indicate the feeding times for the respective replications. Feeding time is reliably followed by an increase in cage activity and, with each successive replication, the point of increase in activity begins earlier. A similar pattern is present for the illumination change measure except that there is a 1-h peak shift plus or minus for Replications A and B₁. There is no apparent cause for the complex form associated with the illumination measure for Replication C.

DISCUSSION

It would appear from these data that feeding time did serve as a reliable entraining stimulus for this squirrel monkey. The period lengths computed by the periodic regression analysis (23.5-24.06) are well within the traditional day lengths for

Table 2
Degrees of Freedom (df), F Ratios (F), and Associated Probability Values (P) from the Periodic Regression
Analysis of Illumination Change Scores for Replications A, B₁, and C

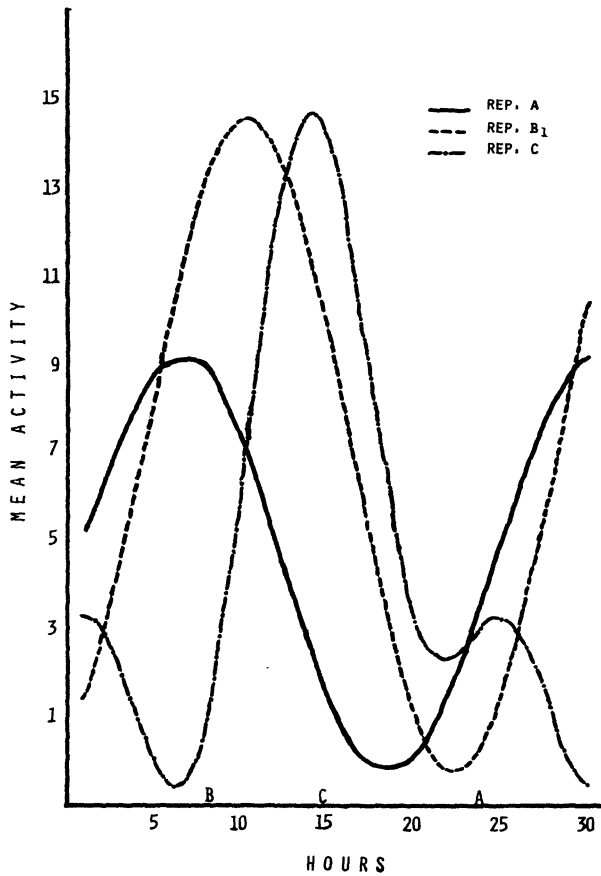| Source	df	Replication A		Replication B₁		Replication C	
		F	P	F	P	F	P
24-h Period	2/378	46.91	< .0001	15.60	< .0001	42.64	< .0001
Scatter	21/378	.73		.89		6.71	< .0001
Days by Amplitude	18/378	3.48	< .001	2.70	< .001	2.74	< .001
Days by Phase	18/378	2.29	< .005	2.17	< .005	4.25	< .001
12-h Period	2/342	–		–		30.43	< .0001
Scatter	19/342	–		–		6.69	< .001
Days by Phase	18/342	–		–		4.50	< .001
8-h Period	2/306	–		–		59.72	< .0001
Scatter	17/306	–		–		1.56	> .05
Cycle Length		24.06		24.03		23.90	

Fig. 1. Best fitting Fourier analysis curves from period regression analysis for Replications A, B_1, and C on the cage activity measure.
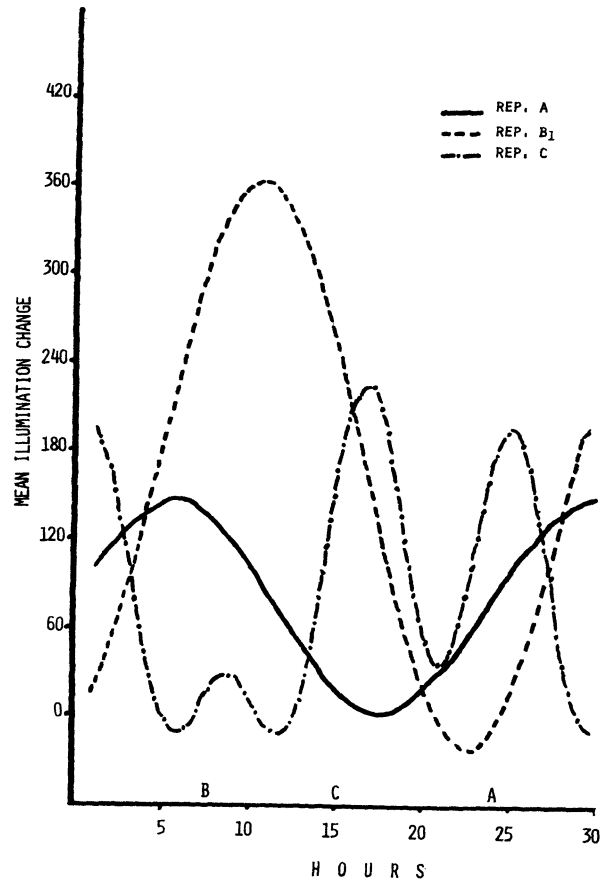

Fig. 2. Best fitting Fourier analysis curves from period regression analysis for Replications A, B_1, and C on the illumination change measure.

circadian rhythms. Further, the phase shift accompanying feeding time shift between Replication A and Replication B_1, as well as the shift between Replication B_2 and Replication C, in the absence of any shift between Replication B_1 and Replication B_2 enhance this claim. Whether feeding time entrainment is, or should be, considered a *major* entraining stimulus cannot be determined from these data. Under the present conditions of continuous self-control of illumination intensity and duration, feeding time appears to reliably control the circadian cycles of both illumination change and cage activity.

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