



An Analysis of Excessive Running in the Development of Activity Anorexia

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BENEKE, W. M., S. E. SCHULTE AND J. G. VANDER TUIG. *An analysis of excessive running in the development of activity anorexia.* *PHYSIOL BEHAV* 58(3) 451–457, 1995.—Food restriction combined with activity wheel access produces activity anorexia: a combination of excessive running, reduced food intake and rapid weight loss. Temporal distributions of running in activity anorexia were examined in a reversal design with one of $2 \times 2 \times 2$ factorial combinations (pelleted-vs-powdered food \times deprivation \times wheel access) as the treatment condition. Wheel revolutions were recorded in 30 min intervals; body weights, food and water intakes were measured daily. Only wheel access combined with food deprivation reliably produced activity anorexia. Excessive running occurred in the absence of schedule-induced polydipsia, was unaffected by food form, and showed distributional characteristics of facultative behavior. These results are inconsistent with schedule-induced behavior explanations. Running distributions appeared consistent with chronobiological models with light/dark onset and feeding serving as zeitgebers.

Activity anorexia Activity Food deprivation Schedule-induced behavior Rats
 Temporal running distribution

RATS (8,13,20,21), mice (8), and golden hamsters (4,5) allowed access to running wheels combined with food deprivation schedules (60–90 min daily food access), ran excessively, ate little and eventually starved. The phenomenon, labelled activity anorexia (7), is characterized by dramatic increases in activity paradoxically associated with decreased food consumption, and has also been observed in some humans diagnosed with anorexia nervosa (10,15,27) as well as some athletes (14,23,26,28). These observations have led researchers (7,9) to suggest that activity anorexia, induced experimentally in rodents, might serve as a useful model for the understanding of anorexia nervosa and its treatment in humans.

Consistent with this notion, Epling and Pierce (7) also observed dramatic increases in running immediately before and after scheduled feeding. They suggested that the running might be a schedule-induced behavior. If water is continuously available during a variable interval schedule of food reinforcement, rats become polydipsic, drinking several times their normal daily water intake (11). The behavior typically manifests itself as an interim schedule-induced behavior, as described by Staddon (24), and has also been obtained with fixed time schedules of reinforcement [e.g., (25)]. If one were to postulate water availability as somewhat analogous to availability of a running wheel, then one could also postulate the excessive wheel running as schedule-induced under the same conditions that produce schedule-induced polydipsia (17,25). Although studies of schedule-induced behavior have utilized small food portions as reinforcers and

brief (commonly 1 min) periodic schedules, at least by analogy, activity anorexia might be a special case of schedule-induced behavior, or the behaviors might share common underlying mechanisms. If true, variables influencing schedule-induced behaviors parametrically should also have parametric effects on activity anorexia.

One such parametric effect might offer an opportunity to explore the relationship between schedule-induced behavior and activity anorexia. Beck, et al. (3) recently demonstrated that changing from a pellet to a powder reinforcer eliminated a broad spectrum of schedule-induced behaviors in rats, including feeder poking, rearing, running and investigating. If there is a common link between schedule-induced behavior and excessive running observed in the exercise-induced anorexia paradigm, then food restriction, combined with access to a running wheel should produce excessive running and anorexia when the available food is in pellet form but not in powder form.

The present study was designed to examine the effect of pellet vs. powder food on activity anorexia. In this context we also set out to carefully describe changes in the daily pattern of wheel-running during the development of activity anorexia.

METHOD

Subjects

Subjects were 84 male Sprague–Dawley rats (SASCO, Omaha, NE), 50–60 days old and weighing 145–245 g at the

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TABLE 1
NUMBERS OF SUBJECTS IN EACH TREATMENT CONDITION REACHING CRITERIA
AND MEDIAN DAYS TO SELF-STARVATION AND SURVIVAL CRITERIA

Treatment Group	n	Numbers Reaching Criteria		Median Days To Criteria	
		Self-Starved	Survived	Self-Starved	Survived
Pelleted	11	0	11	—	4.0
Powdered	11	0	11	—	4.0
Pelleted-Wheel	10	0	10	—	4.0
Powdered-Wheel	10	0	10	—	4.0
Pelleted-Deprived	10	1	9	8.0	11.0
Powdered-Deprived	10	3	7	8.0	7.0
Pelleted-Wheel-Deprived	8	6	2	8.5	13.0
Powdered-Wheel-Deprived	10	8	2	5.5	4.0

start of the study. The rats were housed individually with unlimited access to water throughout the study. Rats were maintained on a photo period of 12/12 h with the lights coming on each morning at 0630 h.

Apparatus

We used standard Wahmann activity wheels (1.125 meters in circumference) equipped with side cages and sliding doors that could be closed to prevent access to the running wheel. The activity wheels were wired to electronic recording equipment located in an adjacent room which recorded wheel revolutions. One wheel revolution was recorded when a rat made a complete revolution in either direction.

Procedure

We ran the experiment in four phases, with rats randomly assigned to one of four conditions on a weight matched basis in each phase. The conditions were 2×2 factorial combinations of wheel access/no wheel access, and food deprivation/no deprivation. In phases one and four, rats were fed a pelleted diet. In phases two and three, rats were fed a powdered diet. Thus, phases one and two combined represent the first replication of a $2 \times 2 \times 2$ factorial design (wheel access \times deprivation \times food type) and phases three and four represent a second replication. We recognized that this approach confounded food type sequence with replication, but the counterbalanced order of pelleted and powdered diet enabled systematic sequential effects to be detected as a significant difference between the first and second replications or a significant interaction involving replications.

The basic procedure consisted of periods for baseline, treatment and recovery. Body weight to the nearest gram, and food and water intakes to the nearest .1 g were recorded daily in all periods. Rats in the pelleted food condition were fed standard Purina Lab Chow throughout the experiment. Lab chow from the same lot was ground to a fine powder and fed to subjects in the powder condition throughout. The remaining variables were effective only during the treatment phase.

Baseline period. Rats had unlimited access to food in their home cages. Weight and intake measurements were begun at 0900 h.

Treatment period. Rats with wheel access (W) were housed in activity wheels in a room separate from, but identical to that of the other rats. When deprived (D), rats were maintained without food for 23 h daily and with food continuously from 1000 h

to 1100 h. Intake for deprived rats was obtained by weighing food cups before and after meal periods. Food intake for the other rats was obtained by weighing the food cups at the same time each day and subtracting the postfeeding weight from the prefeeding weight. Care was taken to retrieve any spillage so as not to include spillage with intake. Water intake was obtained for all rats in the same manner. Access to the wheel was prevented by closing the door between the wheel and side cage during the meal period and during the daily care performed in the preceding hour.

Rats remained in the treatment until they either self-starved or survived. Self-starvation for a rat was defined as a 25% weight loss from its average weight over the last three days of baseline. Survival was defined as a day-four weight of any four day period that was greater than the day-one weight of the same four day period—for example, a day 5 weight greater than day 2 weight or day 7 weight greater than day 4 weight.

This procedure was followed in the first three phases of the study. In phase four, each W rat was yoked to a WD rat so that the nondeprived rat remained in treatment until its yoked partner reached one of the criteria. This change was made to eliminate the possibility that observed differences in amount of activity between the wheel/deprivation rats and the wheel/no deprivation rats were due simply to number of days of exposure to the activity wheel. Statistical comparisons between replications utilized the four days prior to reaching individual criteria for these rats, removing any possible effect of the procedural change from the statistical analysis.

Recovery period. When rats reached one of the criteria they were placed into a recovery period. This period was equivalent to the baseline period with food and water continuously available and animal care begun at 0900 h.

RESULTS

Two pellet-WD rats were eliminated from the study. One was eliminated because of an injured forepaw that might have affected running, and the other because a handling error might have affected data.

No effects involving replication were observed ($p > .05$) for self-starvation/survival rates, food intake, or body weight. Analysis of running for the 38 W and WD rats performed on the mean hourly running of each rat over its last 4 days of treatment also showed no replication effects ($p > .05$). We therefore collapsed all data across replications for subsequent analyses.

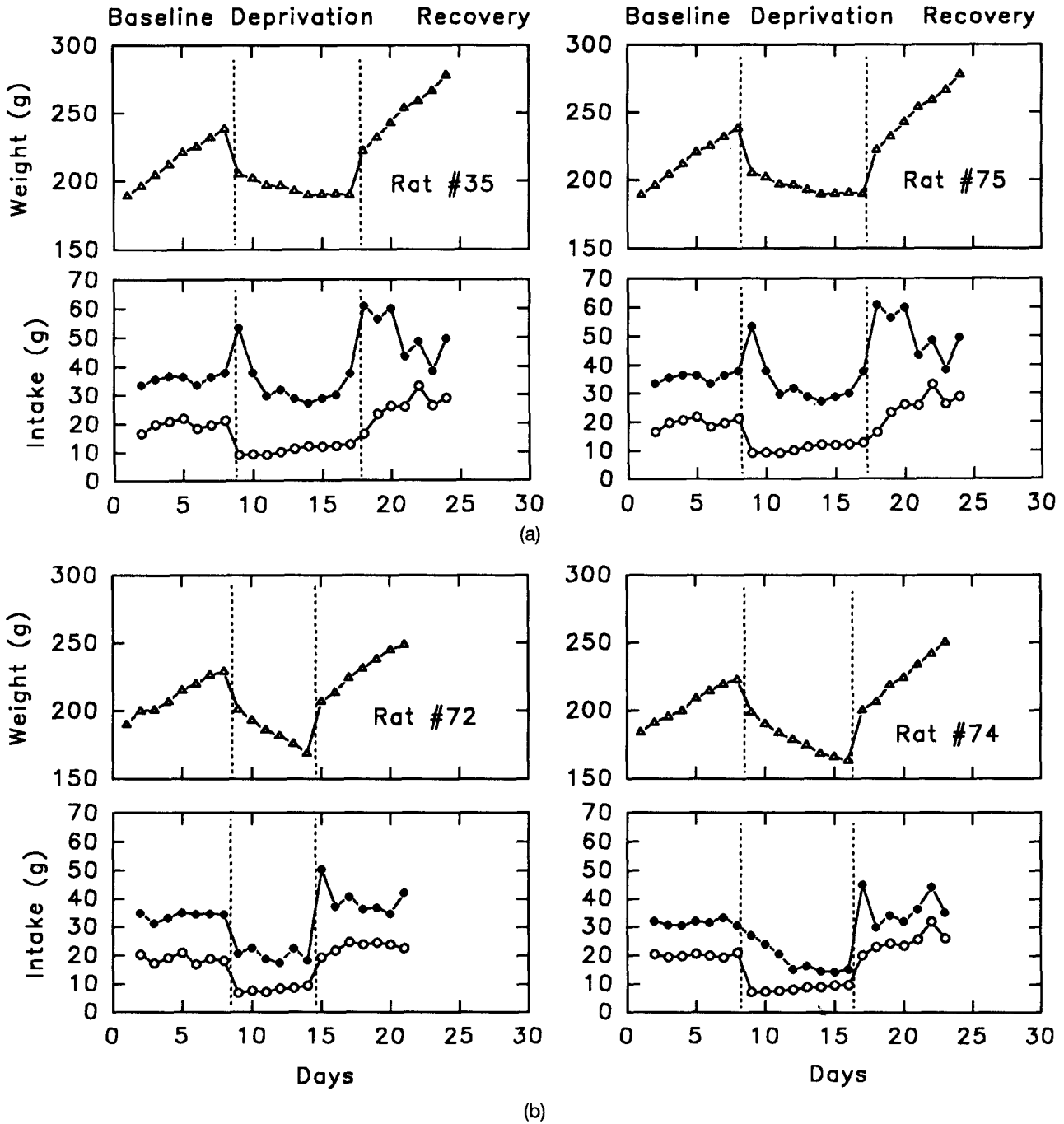


FIG. 1. Body weights, food and water intake during baseline, treatment and recovery periods for (a) two typical surviving rats and (b) two rats reaching self-starvation criteria in the deprivation only conditions. Water intake is shown as filled circles and food intake as open circles.

Incidence of Self-Starvation

Table 1 shows the incidence of self-starvation and survival in each of the eight treatment combinations. Maximum likelihood analysis of variance was performed on self-starvation and survival rates using the SAS Categorical Data Modeling procedure (22). This analysis indicated that food type had no effect on self-starvation/survival rates ($p > .05$); all interactions involving food type were also nonsignificant ($p > .05$). Significant main effects

were observed for both wheel access, $\chi^2(1) = 10.51, p < .0012$, and deprivation, $\chi^2(1) = 19.25, p < .0001$. The wheel access \times deprivation interaction was also significant, $\chi^2(1) = 8.87, p < .0029$. Wheel access did not affect the incidence of self-starvation in rats who were not food restricted: all of these rats continued to gain weight during the treatment phase and met the criteria for survival in the minimum possible period of four days.

Self-starvation developed in four of the 20 deprivation-only (D) rats, and 14 of 18 wheel + deprivation (WD) rats. Separate

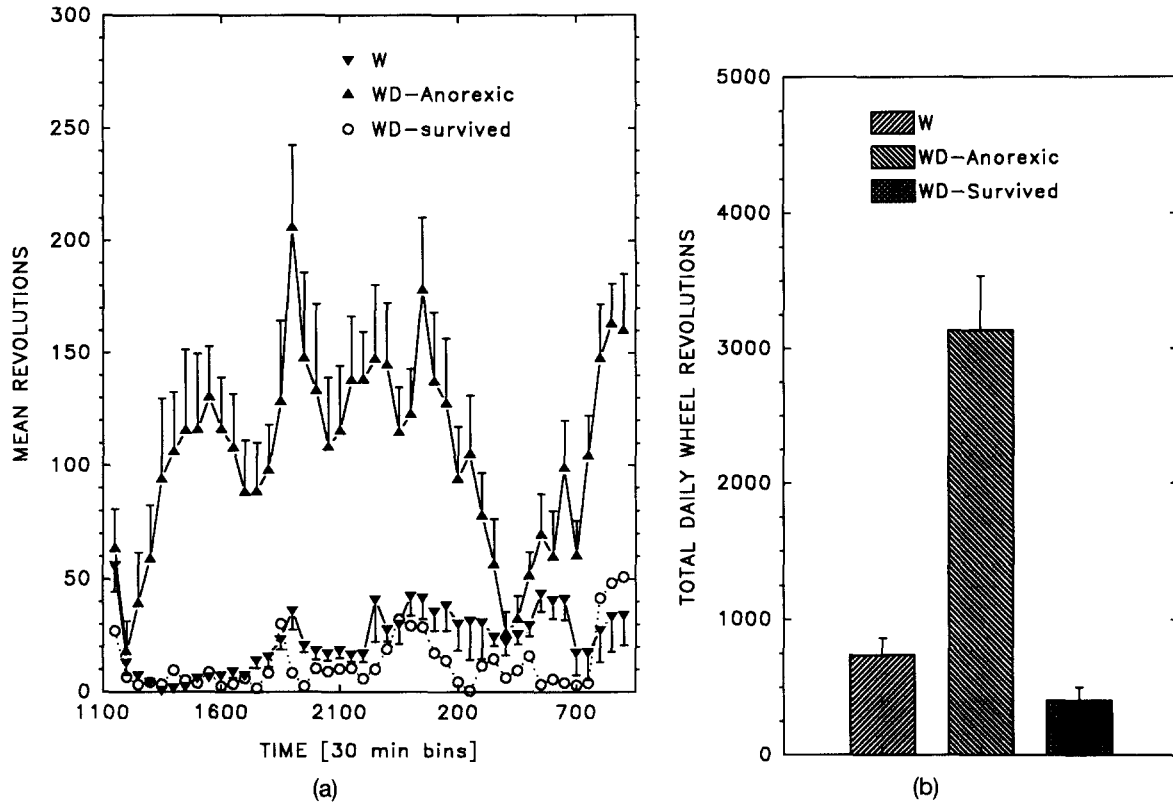


FIG. 2. (a) Distributions of wheel revolutions in consecutive 30 min periods. Because of substantial differences in running between surviving and anorexic rats, the four surviving WD rats were plotted separately; due to their small n , standard errors are not shown. Plotted data are based on means from the last 4 days for each rat, averaged across rats in each grouping. Feeding and animal care preceded period beginning at 1100 h and shown as total at 1130 h. Lights were off from 1830 to 0630 h, shown as totals from 1900 h to 06:30 h. (b) Mean daily totals for the same groups.

analysis of self-starvation/survival rates in those groups experiencing food restriction indicated that wheel access significantly increased the likelihood of self-starvation, $\chi^2(1) = 10.474$, $p < .001$.

Development of Self-Starvation/Survival

Sixteen of the 20 D rats showed a pattern of gradually increasing food intake accompanied by deceleration of weight loss, with weight stabilizing at $82.5\% \pm 1.0\%$ (mean \pm SEM) of weight at end of baseline. Individual data from two typical rats (Fig. 1a) shows the same pattern. Food intake decreased initially, then gradually increased; body weight also dropped initially and then stabilized.

The four self-starving rats (Fig. 1b) showed a sharp initial decline in food intake followed by a gradual increase in daily intake. Although food intake gradually increased and weight loss slowed, the rats reached the 75% ad lib weight criteria for self-starvation before their weight stabilized.

The WD combination resulted in self-starvation in 14 of 18 rats. Self-starving rats completed 3136 ± 401 revolutions (mean \pm SEM), more than four times the mean of 736 ± 126 revolutions completed daily by W rats (Fig. 2). The four surviving WD rats ran very little; their 406 ± 98 average daily wheel revolutions was slightly less than comparable data for the W rats who survived.

At the beginning of the treatment periods food intake decreased and then began to gradually increase for self-starving

WD rats. Initially little running was observed, and gradual weight loss continued (Figs. 3 and 4). This appears similar to the pattern of D rats (see Fig. 1). As running began to accelerate above 5,000 revolutions/day, food intakes declined. The combined effects of reduced intake and the energy cost of running accounts for increased weight loss until rats reached the self-starvation criteria. Once rats were returned to baseline, food and water intakes and body weight increased rapidly.

Water Intake

Group data did not reveal dramatic increases associated with excessive running. The 13.2 g daily average water consumption during treatment for all deprived rats was actually less than the 25.6 g average for all nondeprived rats, $F(1, 67) = 58.23$, $p < .0001$. This also represented a substantial reduction from baseline daily water consumption of 27.9 g in the rats experiencing deprivation. Individual data (Figs. 3 and 4) also did not indicate dramatic increases above baseline in water consumption when relatively large running increases were occurring. To statistically adjust water intake for reduced food consumption, we calculated the regression equation to predict water intake from food intake using mean treatment food and water consumption for each nondeprived rat in the study. We applied that equation to predict water consumption during treatment for deprived rats, and statistically removed the effect of food restriction by calculating residual consumption (obtained-predicted) for each rat. Subse-

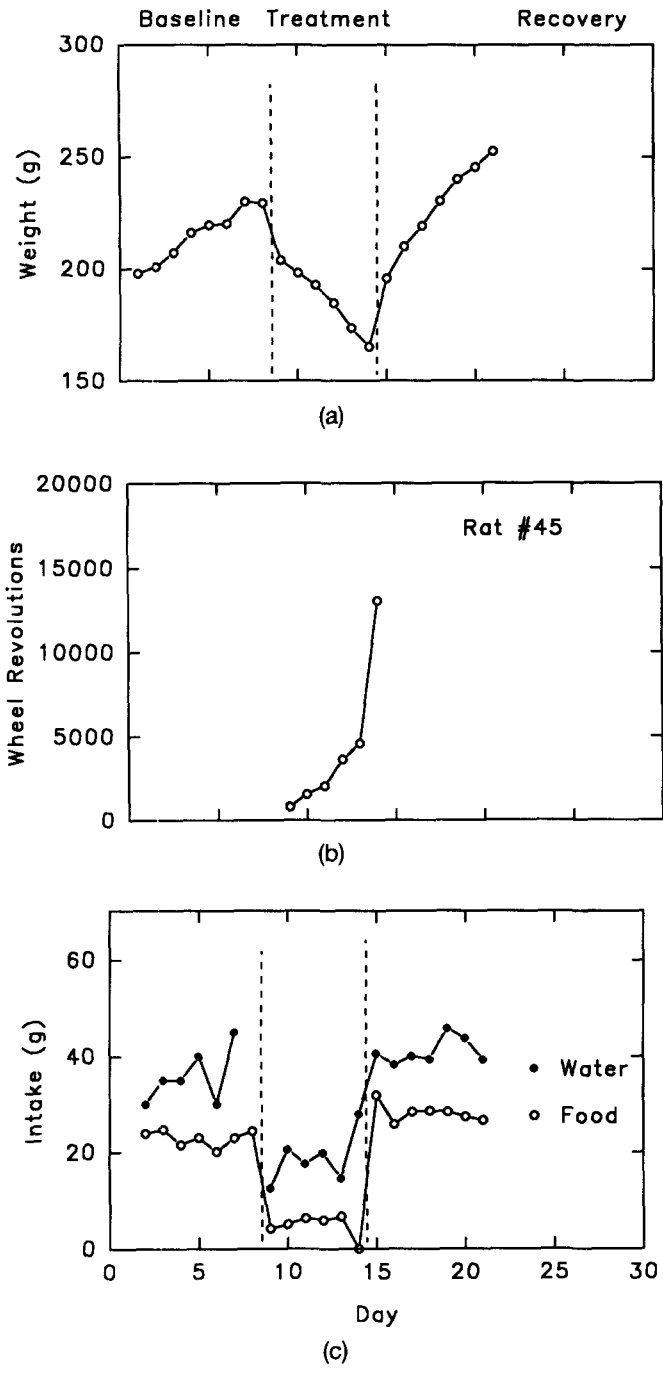


FIG. 3. Data for WD Rat, fed pelleted food. (a) Daily animal weights. (b) Total daily wheel revolutions. (c) Daily food and water intake.

quent ANOVA failed to show any effect of deprivation on residual water intake ($p > .05$).

Distribution of Running Over Time

Temporal running distributions were similar in surviving rats regardless of treatment with most running occurring during the dark period from 1830 h to 0630 h. Increases occurred in the first 30 min following feeding and the 2 h between 0700 h and the

next animal care/feeding. These increases were also observed in running distributions of self-starving rats who, unlike their surviving counterparts, also ran excessively from around 1230 h and through the remainder of the light period. Periods of minimal running (prior to 1230 h and between 0400 h and 0500 h) occurred between this period of highly excessive increase and the preceding and following feeding/care periods.

Data from individual rats also showed these minimal running periods. The dramatic increase in running on day 6 for rat 45

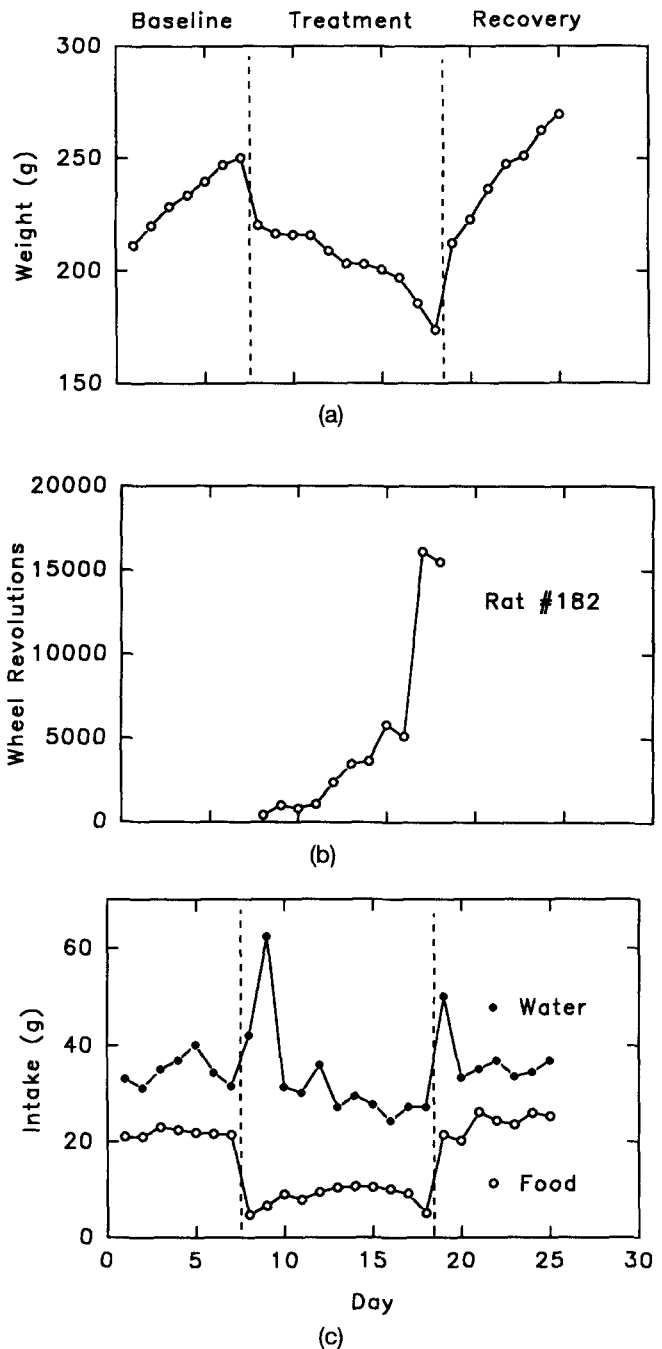


FIG. 4. Data for WD Rat fed powdered food. (a) Daily animal weights. (b) Total daily wheel revolutions. (c) Daily food and water intake.

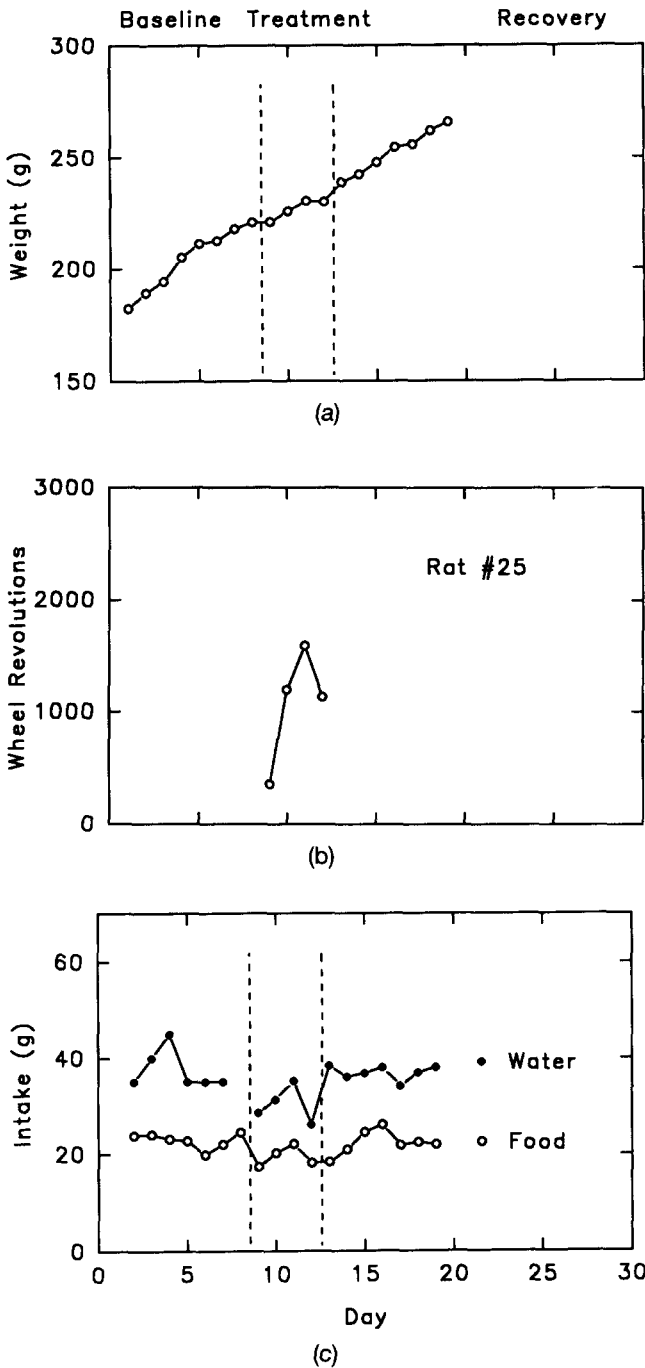


FIG. 5. Data for W Rat, fed pelleted food. (a) Daily animal weights. (b) Total daily wheel revolutions. (c) Daily food and water intake.

(Fig. 3) occurred primarily in two periods (1830 h to 2130 h and 2400 h to 0330 h) with an intervening rest period. Similarly the excessive running for rat 182 (Fig. 4) on days 17 and 18 (10 and 11 of treatment) was due to running between 1830 h and 0330 h. Very little running occurred immediately after feeding for either rat. Both rats showed much lower peaks immediately prior to the next days' care and feeding (0600 h to 0730 h).

These patterns are comparable in distribution (but not magnitude) to running of W rats. Though rat 25 (Fig. 5) ran much

less, its greatest running occurred between 2230 h and 0330 h, with a shorter burst of running occurring in the hour preceding the following days' care/feeding. If any difference in the relative distribution exists it is that self-starving rats begin to run early in the light period following feeding/care.

DISCUSSION

Our results are consistent with the activity anorexia model (7). The pattern of changes over time in food intake, weight and daily running are also comparable to patterns shown in other studies (8) including that with humans (11,27) and with reports of anorexia in endurance athletes (14,23,26,28) and excessive activity in anorexic patients (15).

The excessive amount of daily running observed here and elsewhere also is consistent with the hypotheses that the excessive running is schedule-induced by periodic feeding and that schedule-induced behavior and the activity in activity anorexia share a common underlying mechanism. However, other data from our study are not consistent with either hypothesis.

Firstly, if schedule-induced behaviors occur only with pelleted food, and are eliminated by providing food in a powdered form (3), activity anorexia is not schedule-induced. Providing food in powdered form did not eliminate the excessive running.

Secondly, if the excessive running in activity anorexia is schedule-induced, other schedule-induced behaviors should also be present. Daily water consumption represents a measure of one such behavior and neither group nor individual data showed evidence of schedule-induced polydipsia. The mean daily water consumption during treatment for deprived rats was actually less than that for nondeprived rats.

Since food and water intakes are positively correlated (6), reduction in food intake produced by deprivation could mask polydipsia. This might be important in activity anorexia because increased deprivation accompanies the excessive running. When we examined this further by statistically adjusting water intakes for reduced food consumption we failed to find any effect of deprivation on residual water consumption. The reduced water intake in deprived rats was probably the result of reduced food intake. That relationship has been demonstrated in other contexts (6,16). Thus, activity anorexia developed in the absence of evidence for schedule-induced polydipsia.

Thirdly, distribution of running in the inter-food interval is uncharacteristic of schedule-induced behaviors. In the group running distributions (Fig. 2), the area between the W and WD—Anorexic curves can be seen as representing the excessive running attributable to the periodic food access. A schedule-induced behavior hypotheses would predict that the majority of excessive running would be interim and terminal, falling into periods immediately after and before feeding (18,24). However, little running occurred in the first hour after feeding.

We therefore suggest that schedule-induced behavior does not provide an adequate model for the increased running in activity anorexia, and it appears unlikely that applying knowledge gained from schedule-induced behavior research will contribute to the understanding of anorexia in animals or humans.

Although chronobiological theory appears to contribute little to understanding the amount of running, the observed patterns of daily running in our study are consistent with a chronobiological model of running becoming entrained to both light/dark cycles and periodic feeding (1,2,12,18,19). We observed a substantial increase in running 2 h prior to feeding/animal care in deprived rats and a smaller increase in rats with unlimited access to food. One study which included both a

light/dark cycle and periodic feeding (18) showed that a feeding opportunity served as a zeitgeber (time giver), producing similar anticipatory running. As in the present study, food availability was scheduled in the middle of the light cycle on a standard 12/12 light/dark cycle. Anticipatory running described in other activity anorexia research (7) is also consistent with the notion of feeding opportunity as a zeitgeber. Information obtained from running distributions over the inter-food interval in conjunction with the biological rhythm literature may prove useful in the planning and design of fu-

ture research to uncover the causal relationships in activity anorexia.

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