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Influence of Meal Frequency and Timing on Physical Activity and Body Weights of Rats[1] (39693)

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Allowing human beings to eat a 2000-kcal meal in the morning resulted in a greater weight loss than when the 2000-kcal meal was consumed in the evening (1). These individuals were physically active during the day and inactive at night. In other studies it was noted that humans exercised after a meal, consume more oxygen than can be accounted for by the additive effects of the meal and the exercise (2-4). Mice allowed to eat only at the onset of darkness each day, i.e., at the onset of their usual active period gained less weight than mice forced to eat at the onset of light (5). Also rats forced to eat from 8 to 10 AM, which is during their usual period of inactivity, are more efficient than *ad libitum* fed rats in converting food energy to body weight gain (6-8). These observations suggest that the timing of the meal relative to periods of physical activity may be an important determinant in the regulation of energy metabolism.

The purpose of the experiments reported here was to examine the influence of meal-timing relative to the pattern of physical activity on body weight gain and epididymal fat pad weights of rats. Rats were fed three different diets either at the beginning of their usual period of inactivity (8 AM) or at the beginning of their usual period of high physical activity (7 PM). Meters were utilized to monitor physical activity of the rats.

Materials and methods. For study, male Sprague-Dawley rats[2] were housed in individual metal cages (18 × 24 cm) with raised wire floors or in plastic shoe-box cages (20 × 45 cm) with wood shavings as bedding. Meal-fed rats were allowed to eat from 8 AM to 10 AM or from 7 PM to 9 PM. Water was available *ad libitum*. Room lights were on from 7 AM to 7 PM. Body weights of the rats were recorded just before the meal or for *ad libitum* fed rats at 10 AM. Three semipurified diets were fed (Table I). Five experiments were conducted.

Activity meters[3] were utilized to obtain estimates of physical activity. Rats housed in shoe-box cages were placed on the top plate of a meter. Animal movements were sensed as the animal moved about the cage, and their movements were recorded on a digital readout. Four meters were utilized. An animal was on one meter for 24 hr and then rotated to another meter. Movements of all animals were recorded on each meter during an experiment; thus any sensitivity differences among the four meters in detecting movements would not influence the treatment results. A constant and minimal quantity of bedding was added to each cage when activity was recorded.

In experiments III-V, rats were killed to obtain an estimate of epididymal fat pad weights. Animals fed from 8 to 10 AM were killed at 8 AM, and animals fed from 7 to 9 PM were killed at 7 PM.

Rats were pair-fed in experiments III-V. Based on the food intake of animals fed from 8 to 10 AM, animals were given an equal amount of food at 7 PM. These rats generally consumed their food within 30 min.

Results. Rats, weighing 250 g initially, were fed from 8 to 10 AM or were allowed *ad libitum* access to Diet 1 for 4 wk. Their physical activity was then recorded (Table II). Based on estimates obtained with the activity meters, the total daily movements of the rats were not influenced by the meal pattern. Regardless of meal pattern, the rats were most active during the dark hours.

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[2] Spartan Research Animals Inc., Haslett, Michigan.

[3] Columbus Instruments Co., Columbus, Ohio.

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Forcing the rats to eat during the light hours did alter their circadian pattern of physical activity; however, 68% of their activity still occurred during the dark hours.

In a second experiment, rats were fed a 2-hr meal during the light hours or during the dark hours. Total physical activity was not influenced by meal pattern (Table III). Rats fed in the morning were more active from 8 to 10 AM than rats fed in the evening. Again, 70–75% of the rats' activity occurred during the dark hours.

Food intake and body weights of rats offered a high-carbohydrate diet from 8 to 10 AM or from 7 to 9 PM (experiments II and III) were recorded. Food intake and body weight gain of these rats was not influenced by the feeding pattern (Table IV). In experiment III, one group of rats was also pair-fed. Body weight gain of these rats was similar to that observed in rats fed from 8 to 10 AM or from 7 to 9 PM. Likewise, the epididymal fat pad weights of these rats were not influenced by the feeding pattern.

It is possible that the composition of the diets fed to the rats might influence the relationship of meal-timing and physical activity to body weight gain. In experiments IV and V, diets containing intermediate and high levels of fat were fed (Table IV). Again, neither body weight gain nor epididymal fat pad weights were influenced by the timing of the meal.

Discussion. Rats allowed to eat from 8 to 10 AM appear to be more efficient than *ad libitum* fed rats in converting diet consumed to body weight gain (7, 8). In a previous report, spontaneous activity of the rats was determined in revolving cages (7). Meal-fed rats exhibited a reduced spontaneous activity level. It was suggested that the reduced activity of the meal-fed rats might account for their improved energy efficiency. However, in the present study, total activity of the meal-fed rats as estimated with electronic activity meters was not reduced. These results would suggest that factors other than alterations in physical activity are involved in the improved food efficiency of the meal-fed rat. Unfortunately, data obtained with the activity meters did not allow calculation of actual energy expenditure associated with physical movement but, rather, gave only an estimate of the relative activity among the two groups of rats. It has been noted that physical activity contributes relatively little to the total daily energy expenditure of the rat (3, 6, 10).

A shift in the meal from 8–10 AM to 7–9 PM influenced the pattern of physical activity of the rats only minimally (Table III). However, in neither animals allowed to eat a high-carbohydrate diet in the morning or in the evening nor in pair-fed animals did the timing of the meal influence body weight gain or epididymal fat pad weights.

Consumption of the intermediate and high-fat diets should have altered the

TABLE I. COMPOSITION OF THE DIETS.

	Diet		
	I (g)	II (g)	III (g)
Basal[a]	33.9	33.9	33.9
Glucose	66.1	33.0	0.0
Tallow	0.0	15.0	30.0
Total	100.0	81.9	63.9

[a] The basal mix contained (in grams/33.9 g): casein, 20.0; methionine, 0.3; mineral mix, 4.0 [see Ref. (7)]; vitamin mix, 0.4 [see Ref. (7)]; choline chloride, 0.2; cellulose, 4.0; and corn oil, 5.0.

TABLE II. PHYSICAL ACTIVITY OF MEAL-FED AND *ad libitum* FED RATS, EXPERIMENT 1, DIET I[a].

		Percentage of total		
	Total activity per day	8–10 AM	10 AM–7 PM	7 PM–7 AM
Fed 8–10 am	19,203 ± 515	13.2 ± 1.4	18.0 ± 1.5	67.7 ± 2.3
Ad libitum fed	18,358 ± 584	2.4 ± 0.9[b]	9.2 ± 2.3[b]	87.4 ± 3.6[b]

[a] Mean ± SEM of activity meter recording per day for eight rats. Activity of each rat was determined on 4 separate days from Day 28 to 44 of the experiment. Meal-fed rats weighed 365 ± 11 g after 28 days, gained 36 ± 3 g, and consumed 129 ± 10 g food from 28 to 35 days whereas *ad libitum* fed rats weighed 411 ± 9 g after 28 days, gained 33 ± 4 g, and consumed 154 ± 8 g food from 28 to 35 days on the experiment.

[b] Meal fed versus *ad libitum* fed, significantly different, $P < 0.05$.

TABLE III. PHYSICAL ACTIVITY OF RATS MEAL-FED IN THE MORNING OR IN THE EVENING, EXPERIMENT II, DIET I[a].

Time of feeding	Total activity per day	Percentage of Total			
		8–10 AM	10 AM–7 PM	7 PM–9 PM	7 PM–7 AM
8–10 AM	15,042 ± 532	10.7 ± 0.7	17.9 ± 0.9	16.2 ± 1.1	69.7 ± 3.2
7–9 PM	14,135 ± 863	4.3 ± 0.5[b]	19.1 ± 1.1	16.4 ± 1.4	75.3 ± 4.4

[a] Mean ± SEM of activity meter recordings per day for eight rats. Activity of each rat was determined on 4 separate days from Day 19 to 35 of the experiment. Body weight and food intake data are presented in Table IV.
[b] AM versus PM, significantly different, $P < 0.05$.

TABLE IV. EFFECT OF MEAL-TIMING ON FOOD INTAKE, BODY WEIGHT GAIN, AND EPIDIDYMAL FAT PAD WEIGHTS IN RATS[a].

	Time of Meal		
	8–10 AM	7–9 PM	7 PM—pair-fed to AM rats
Experiment II (Diet I)			
Initial weight (g)	180 ± 3	180 ± 3	–
Food intake (g)	473 ± 22	486 ± 15	–
Body weight gain (g)	93 ± 11	88 ± 7	–
Experiment III (Diet I)			
Initial weight (g)	220 ± 4	219 ± 5	220 ± 5
Food intake (g)	520 ± 20	560 ± 32	520 ± 20
Weight gain (g)	92 ± 6	114 ± 7	93 ± 8
Epididymal fat pad (g/100 g body wt)	122 ± 0.07	1.17 ± 0.08	1.29 ± 0.07
Experiment IV (Diet II)			
Initial weight (g)	236 ± 3	–	235 ± 3
Food intake (g)	547 ± 30	–	544 ± 28
Weight gain (g)	112 ± 7	–	123 ± 5
Epididymal fat pad (g/100 g body wt)	1.71 ± 0.08	–	1.84 ± 0.07
Experiment V (Diet III)			
Initial weight (g)	235 ± 4	–	236 ± 3
Food intake (g)	480 ± 25	–	478 ± 27
Weight gain (g)	148 ± 8	–	146 ± 12
Epididymal fat pad (g/100 g body wt)	2.38 ± 0.14	–	2.59 ± 0.21

[a] Mean ± SEM for 10 rats. Rats in experiment II were fed for 5 weeks whereas rats in experiments III–V were fed for 6 weeks.

plasma insulin to glucagon ratio in the rats. However, the body weight gains and epididymal fat pad weights of rats fed these diets were not influenced by the timing of the meal. Thus, the reported calorigenic action of glucagon (9) did not appear to be potentiated by a shift in the rats' meal pattern.

The reported synergistic action of meal-timing and physical activity on energy metabolism in humans (1–4) was not evident in the present study. The methods utilized (body weight gain and epididymal fat pad weights) may have lacked the sensitivity necessary to detect possible effects; however, body weight changes were evident in humans within one week after shifting the meal pattern. Alternatively, the rat may not be an appropriate animal model for such studies since the energy cost of physical activity for the rat is a negligible proportion of its total energy requirement (3, 6, 10). Carefully controlled long-term studies in humans or in animals with body weights similar to humans are needed to evaluate the possible interaction of meal-timing and physical activity in the control of energy balance.

Summary. Rats fed from 8 to 10 AM exhibited the same total physical activity per day as did *ad libitum* fed rats. Likewise rats fed from 7 to 9 PM did not alter their total activity. As expected, all rats were most

active when the lights were out. A shift in time of feeding did not influence body weight gain or epididymal fat pad weights of the rats. An interaction between meal-timing and physical activity in the control of body weight was not evident in the present study with rats.

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