Pheromone-induced anorexia in male Syrian hamsters

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Morgan, Caurnel, Henryk F. Urbanski, Wei Fan, Huda Akil, and Roger D. Cone. Pheromone-induced anorexia in male Syrian hamsters. Am J Physiol Endocrinol Metab 285: E1028–E1038, 2003.—Transition from long days (LDs) to short days (SDs) triggers seasonal obesity in Syrian hamsters. We report here that SD-exposed males housed near females exhibit obesity resistance, episodic weight loss, and reduced adiposity. Negative energy balance is achieved by reduced eating, elevated motor activity, and increased caloric efficiency without metabolic compensation. Circulating leptin, insulin, testosterone, corticosterone, and cortisol are normal or reduced in obesity-resistant hamsters. When males are housed in chambers that block physical, visual, and auditory, but not pheromonal, signals from females, resistance to seasonal obesity persists. Moreover, inhalation of extracts from pheromone-releasing flank glands of females suppresses eating and weight gain in SD-exposed males. This novel phenomenon, pheromone-induced anorexia, shows that female pheromones play a critical role in the seasonal energy balance of male hamsters. These findings provide a model to study neural and endocrine mechanisms that underlie eating disorders.

Mesocricetus auratus; hypocaloric; hypercaloric; locomotor activity; oxygen consumption

ANIMALS THAT INHABIT temperate and polar regions have high energy demands during autumn and winter. Decreases in ambient temperature and food availability follow seasonal shortening of day length (4). Accordingly, mechanisms for seasonal energy conservation have evolved in many warm-blooded species. Behavioral mechanisms can increase energy availability through increased feeding, decreased motor activity, and food hoarding. Physiological mechanisms can reduce energy expenditure through increased fur density, increased body fat deposition, and reduced metabolic activity (e.g., hibernation). Although factors such as food availability, dietary fat content, and ambient temperature play an important role, day length is the most reliable environmental trigger for these energy-conserving mechanisms (7, 34). For the purpose of this study, long days (LDs) and short days (SDs), respectively, contain more and less than ~12 h of light per day (13).

Numerous reports have characterized seasonal changes in the behavior and physiology of hamsters (7). Syrian hamsters are known to exhibit seasonal obesity (i.e., accelerated weight gain and increased adiposity) during SD exposure. This form of seasonal energy conservation is achieved by reduced motor activity (7, 10) without appetitive or metabolic compensation (6, 53). In addition to this behavioral response that promotes energy conservation in hamsters, there are other behavioral and physiological responses that may act on energy balance during SD exposure.

Seasonal breeding has been characterized particularly well in Syrian hamsters. SD exposure decreases gonadal function (31) and mating behavior (35, 44) in male and female hamsters. Although these effects on reproductive behavior and physiology reduce the birth of offspring under unfavorable environmental conditions, they may also promote seasonal energy conservation. Decreased circulating levels of testosterone in males and estrogen in females promote body fat deposition in mammals (11, 47, 49, 50). Moreover, pregnancy, parturition, and lactation are energetically costly. Although they have not been investigated extensively, seasonal changes in adrenal function occur in Syrian hamsters. As in humans, the hamster adrenal cortex secretes two corticosteroids, corticosterone and cortisol (1, 32, 41). For hamsters, corticosteroid secretion increases during the active portion (i.e., the dark phase) of the 24-h light-dark cycle (1, 42). SD exposure elevates corticosterone secretion in the light phase and reduces cortisol secretion in the light and dark phases, thereby elevating the corticosterone/cortisol ratio (42). Although elevated corticosteroid activity promotes body fat deposition in mammals (20, 40), the physiological relevance for changes in the corticosterone/cortisol ratio in hamsters is not clear, but an important consequence may be energy conservation through behavioral adaptation. Syrian hamsters are more aggressive during SDs (3, 26, 30, 33), and they hoard more...
food when availability is limited (43), as would be expected during SDs. Seasonal changes in adrenal function may play a role in the defense of hoarded food, since corticosteroids are critical for the circadian rhythm of aggression in hamsters (37).

There is considerable adaptive value in seasonal obesity as a form of energy conservation. It was, therefore, surprising to find in preliminary experiments that male hamsters were resistant to seasonal obesity under our experimental conditions. After reviewing the findings of others, we discounted age, sex, diet, ambient temperature, SD length, initial body weight, and housing density from playing a major role in this unusual obesity resistance. Because the obesity-resistant males were housed near female hamsters, we hypothesized the existence of a suppressive female influence. To test the hypothesis, we investigated effects of male-female interactions on weight gain and eating in hamsters exposed to LDs and SDs.

MATERIALS AND METHODS

Animals. Syrian golden hamsters (Mesocricetus auratus) were purchased at 8 wk of age. For the sensory isolation experiments, hamsters were purchased from Charles River Laboratories (Wilmington, MA). For the remaining experiments, hamsters were purchased from Harlan Sprague Dawley (Indianapolis, IN). Procedures used in this study were approved by institutional Animal Care and Use Committees. Hamsters were maintained in accordance with US Department of Agriculture guidelines.

Animal housing. Hamsters were group-housed in the sensory isolation (6/cage) and pheromonal signal-screening (4/cage) experiments, and individually housed in the other experiments. In the sex-mixed condition, male hamsters were housed on shelves directly above females. Thus, under these conditions, the male hamsters were exposed to volatile female pheromones but were prevented from making physical and visual contact with the females. In the sex-isolated condition, male hamsters were housed in rooms without females. Care was taken not to enter sex-isolated rooms after eating. In the sex-isolated condition, the male hamsters were pheromonally isolated from female hamsters. Animals were acclimated to LDs (14:10-h light-dark cycle) for ≥2 wk. Some of the hamsters in each experiment were transferred to SDs (10:14-h light-dark cycle). Room temperatures were 22 ± 2°C.

Animal diets. Food and tap water were provided ad libitum. The low-fat diet consisted of Purina Rodent Chow (Diet 5001; 12.8% fat calories, 3.04 kcal/g). The moderate-fat diet consisted of Purina Breeder Mouse Chow (Diet 5015; 25.1% fat calories, 3.73 kcal/g). Weekly food intake was determined for individually housed animals only.

Motor activity. Home cage activities of individually housed hamsters in the dark phase were videotaped over a 2-h period by using an infrared light source on a TR-V65 Hi8 video camera (Sony, New York, NY). Locomotor activity was estimated from lateral ambulations (traversing the cage). General motor activity was estimated from incidences of rearing on the hindlegs and climbing onto the cage lid. Three-second bouts of digging in the bedding were used to assess food-seeking (27) and/or escape (24) behaviors. Three-second bouts of stereotyped motor activity (self-grooming) were used to assess stress-coping behavior (19). The behaviors were scored from the videotapes by trained observers, and scores of two observers were averaged.

Metabolic activity. Animals were habituated by placing them in the metabolic chambers on three successive days for 2 h. On day 4, measurements were recorded. Metabolic activity was measured over a 4-h period during the light phase by indirect calorimetry in an Oxymax System (Columbus Instruments, Columbus, OH), as previously described (23). Food and water were unavailable during the testing. Airflow rate was 1.25 l/min. Exhaust air was sampled at a rate of 1 l/min at 15-min intervals for 50-s periods. Room temperature was 22 ± 1°C. Metabolic activity of male hamsters was assessed in the absence and presence of females for isolated and mixed conditions, respectively. Sampled air was sequentially passed through sensors for the determination of oxygen and carbon dioxide content. Oxygen consumed (V02) and carbon dioxide produced (VCO2) (mg·h−1·kg−2/3) were determined, the metabolic rate (10−2 kcal·h−1·kg−2/3) was determined, and the respiratory exchange ratio (RER; VCO2/V02) was calculated.

Sensory isolation. Group-housed male hamsters were isolated in chambers constructed of 19-mm plywood (1 × 0.5 × 1 m). Inside surfaces were painted black, and tight-fitting doors sealed the chambers. In each chamber, two 100-W incandescent lamps controlled by an electric timer provided light. A wall-mounted electric fan drew air into the chamber (ventilation rate: 10 vol/h) through a small, light-proof baffle padded with gauze. The chamber temperature was 23 ± 1°C. Male hamsters housed within the sealed chambers were isolated from physical, visual, and auditory contact with the outside, but not olfactory signals of female hamsters that were housed 4 m away.

Flank glandectomy. Female hamsters were anesthetized with an intraperitoneal injection of 100 mg/kg ketamine and 10 mg/kg xylazine. Hair covering the flanks was shaved with electric shears. A skin-deep incision was made with surgical scissors to excise the darkly pigmented flank gland. Wound clips were used to close the incisions. Surgically altered hamsters were individually housed and used as pheromone donors for LD- and SD-exposed male hamsters.

Pheromone treatments. Female hamster secretions were collected postmortem. For flank gland secretion (FGS), each pair of flank glands was dissected and shaken in 2.5 ml of sterile water for 1 min (FGS1M) or homogenized in 2.5 ml of 50% ethanol (FGS50). Particulate material was removed by sedimentation. FGS extracts were diluted to 10 ml with sterile water. For vaginal gland secretion (VGS), 1 ml of sterile water was infused into the vaginal opening, collected with a 1-ml pipette, and diluted to 10 ml with sterile water. For bladder urine (BU), by use of a 1-ml syringe fitted with a 27-gauge needle, 1 ml was collected from the urinary bladder and diluted to 10 ml with sterile water. Diluted secretions were stored at −20°C. Effects of female secretions were assessed in two experiments. All treatments were carried out late in the light phase. In one experiment, 12-wk-old group-housed male hamsters were exposed to LDs or SDs in sex-isolated rooms for 10 wk. Males were removed from their cage rooms two to three times weekly and permitted to sniff cotton swabs soaked in FGS50, VGS, BU, or vehicle. In the follow-up experiment, 15-wk-old group-housed male hamsters were individually housed and exposed to LDs or SDs in sex-isolated rooms. FGS50 (0.3 ml) was added to the bedding twice weekly for 12 wk. In these experiments, initial body weights were greater than in other experiments.

Tissue collection. After the hamsters were killed by decapitation, trunk blood was collected in sterile tubes on ice.
Testes, adrenal glands, and spleens were excised, trimmed of fat and connective tissue, and weighed.

Radioimmunoassays. Hamsters were killed by decapitation during the light phase without fasting. Trunk blood was centrifuged at 3,000 g and 4°C for 10 min to derive serum. Leptin and insulin were measured using multispecies RIA and sensitive rat RIA kits, respectively (Linco, St. Charles, MO). Intra-assay variations were ~2 and ~4%, respectively. Limits of detection were ~1.5 and ~0.1 ng/ml, respectively. Serum total testosterone, corticosterone, and cortisol were measured using Coat-a-Count RIA kits (Diagnostic Products, Los Angeles, CA). Intra-assay variations were ~3%, ~8%, and ~5%, respectively. Limits of detection were ~0.5 pg/ml, ~6 ng/ml, and ~2 ng/ml, respectively. For all hormones, duplicate samples were assayed according to manufacturers’ instructions and in single assays to eliminate interassay variation.

Statistical analyses. Repeated-measures ANOVA and Bonferroni’s test (post hoc analyses) were used to determine statistical effects of SDs, time, and their interactions in the time course experiments. Student’s t-test was used to determine statistical differences between means (±SE) for data shown in all other experiments (*P < 0.05, **P < 0.01). All statistical analyses were performed using SigmaStat version 2.0 statistical software (Jandel, Chicago, IL).

RESULTS

In the first experiment, we individually housed adult male hamsters in sex-isolated or sex-mixed conditions. Hamsters in both conditions were exposed to LDs or SDs for 10 wk. For LD-exposed males, body weight increased by 23% in the isolated condition and 25% in the mixed condition. Because these increases were statistically similar, the data were combined (Fig. 1A). For SD-exposed males, body weight increased by 34% in the isolated condition and only 9% in the mixed condition (Fig. 1A). For LD-exposed males, food intake and other experimental parameters were similar in the isolated and mixed conditions. Therefore, these data were combined in Fig. 1B and in subsequent figures.

![Fig. 1](http://ajpendo.physiology.org/) Effects of sex isolation on seasonal energy conservation. Male hamsters were individually housed in sex-isolated or -mixed rooms and exposed to long (LDs) or short days (SDs) for 10 wk. Data for isolated and mixed hamsters exposed to LDs were combined, as they did not differ significantly. A: compared with LD/Combined conditions (n = 8), SD/Isolated condition (n = 5) elevated weight gain, and the SD/Mixed condition (n = 5) reduced weight gain. B: SD/Isolated condition did not alter food intake, but SD/Mixed condition reduced food intake. C: SD/Isolated condition elevated caloric efficiency, and SD/Mixed condition reduced caloric efficiency. Means ± SE are shown. For LD/Combined vs. SD/Isolated and LD/Combined vs. SD/Mixed comparisons, *P < 0.05 and **P < 0.01.
For SD/Isolated males, food intake did not differ from that of LD/Combined males, but the SD/Mixed condition reduced food intake (Fig 1B). For SD/Mixed females, weight gain was elevated, but food intake did not differ compared with LD/Mixed females (data not shown).

Caloric efficiency (g body wt gained/kcal of food eaten) was calculated as an index of energy conservation. Compared with the LD/Combined condition, the SD/Isolated condition increased caloric efficiency, indicating elevated energy conservation, and the SD/Mixed condition decreased caloric efficiency, indicating reduced energy conservation (Fig. 1C). For SD/Mixed females, caloric efficiency was elevated compared with LD/Mixed females (data not shown).

Energy expenditure was assessed by measuring motor and metabolic activities. Motor activity in the home cage was further divided into lateral, rearing, climbing, digging, and grooming behaviors. Compared with the LD/Combined conditions, the SD/Isolated condition reduced energy expenditure by decreasing lateral, rearing, and climbing behaviors, and the SD/Mixed condition stimulated energy expenditure by increasing the same behaviors (Fig. 2A). Digging behavior was unaffected by SD exposure in either condition (Fig. 2A). Grooming behavior was elevated in the SD/Mixed condition only. 

Cortisol (Fig. 2A) was reduced by SD exposure in the isolated and mixed conditions (Fig. 3C). Adrenal gland weight was also reduced by SD exposure in the isolated and mixed conditions (Fig. 3D). Spleen weight was not altered by the treatments (Fig. 3E).

Circulating levels of several hormones that regulate body weight and adiposity, through feeding and metabolism, were measured. Leptin (Fig. 4A) and insulin (Fig. 4B) were unaffected in the SD/Isolated and SD/Mixed conditions compared with LD/Combined males. Testosterone (Fig. 4C) was reduced by SD exposure in the isolated and mixed conditions. Corticosterone was not altered by the treatments (Fig. 4D). Cortisol (Fig. 4D) was reduced by SD exposure in the isolated and mixed conditions.

We assessed effects of female pheromonal signals on male weight gain. SD-exposed male hamsters were group housed in chambers that blocked physical and visual signals and markedly attenuated auditory signals. Volatile pheromonal signals from LD-exposed female hamsters were drawn into the chambers through ventilation ports. Because of limited space in the chambers, we exposed group-housed males to LDs in the mixed-sex condition, but our findings (Figs. 1–4) dem-
onstrated that proximity to females did not alter any measured aspect of their energy balance. After 18 wk, LD-exposed pheromone-treated (LD/Φ) males increased in body weight by 86%, but weight gain in SD/Φ males was limited to 42% (Fig. 5A). Testis weight was markedly reduced in SD/Φ males (Fig. 5B). When males were transferred back from 11 wk of SDs to 1 wk of LDs while exposed to female pheromones (SD/LD/Φ), weight gain (Fig. 5C) and testis weight increased (Fig. 5D) compared with SD/Φ males.

To locate the source of the suppressive pheromonal signal, we used group-housed males in the SD/Isolated condition and permitted them to sniff vehicle or one of three secretions from LD-exposed females. The secretions included FGS_{H2O}, VGS, and BU. SD-exposed males treated with VGS, BU, or vehicle did not differ in weight gain, and the data were combined (SD-combined). We also used vehicle-treated males in the LD/Isolated condition. Compared with LD/Vehicle treatment, SD-combined treatment elevated weight gain. SD/FGS_{H2O} treatment suppressed weight gain to the level of LD/Vehicle treatment (Fig. 6A). In LD/Mixed males, moderate dietary fat promoted reductions in weight gain between weeks 1 and 10, including weight loss in 4 of the final 6 wk (Fig. 7A). In LD/Mixed males, moderate dietary fat promoted an increase in food intake (hyperphagia) until week 3, a transient reduction in food intake (hypophagia) at week 5, and typical food intake (normophagia) at weeks 4 and 6–10 (Fig. 7B). After the increase in dietary fat, SD/Mixed males exhibited normophagia during weeks 1–3 and hypophagia from weeks 4–10 (Fig. 7B). Because of the elevated caloric content of the

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Fig. 3. Effects of sex isolation on seasonal changes in tissue weights. Male hamsters were individually housed in sex-isolated or -mixed rooms and exposed to LDs or SDs for 10 wk. Data for LD/exposed isolated and mixed hamsters were combined, as they did not differ significantly. A: compared with LD/Combined conditions (n = 8), SD/Isolated condition (n = 5) did not significantly alter white adipose tissue (WAT) weight. SD/Mixed condition (n = 5) reduced WAT weight in epididymal but not inguinal fat pads. B: SD exposure reduced testis weight, whether measured as absolute or normalized (per 10 kg body wt), in both isolated and mixed conditions. C: SD exposure reduced absolute and normalized adrenal gland weight in both isolated and mixed conditions. D: SD exposure did not alter absolute or normalized spleen weight. For LD/Combined vs. SD/Isolated and LD/Combined vs. SD/Mixed comparisons, *P < 0.05 and **P < 0.01.

with LD/FGS_{EtOH} treatment, SD/FGS_{EtOH} treatment suppressed food intake (Fig. 6B) and weight gain (data not shown). Reduction of caloric efficiency indicated decreased energy conservation following FGS_{EtOH} treatment (data not shown). When males were individually housed in the mixed-sex condition with females subjected to surgical removal of the flank glands, during weeks 6–9 of exposure to SDs, female suppression of weight gain (Fig. 6C) and food intake (Fig. 6D) were not observed.

Finally, we assessed responses of sex-mixed hamsters to elevated dietary fat for 10 wk. In LD/Mixed males, the switch from a low-fat diet (12.8% fat calories) to a moderate-fat diet (25.1% fat calories) promoted normal weight gain until week 3, reductions in weight gain between weeks 4 and 6, and modest weight gain between weeks 5 and 10 (Fig. 7A). The combination of SD/Mixed condition and moderate dietary fat promoted reductions in weight gain between weeks 1 and 10, including weight loss in 4 of the final 6 wk (Fig. 7A). In LD/Mixed males, moderate dietary fat promoted an increase in food intake (hyperphagia) until week 3, a transient reduction in food intake (hypophagia) at week 5, and typical food intake (normophagia) at weeks 4 and 6–10 (Fig. 7B). After the increase in dietary fat, SD/Mixed males exhibited normophagia during weeks 1–3 and hypophagia from weeks 4–10 (Fig. 7B). Because of the elevated caloric content of the
moderate-fat diet, LD/Mixed males exhibited hypercaloric eating, except at week 5 when they were normocaloric (Fig. 7C). SD/Mixed males exhibited hypercaloric eating during weeks 1 and 2, normocaloric eating during weeks 3–8, and hypocaloric eating during weeks 9 and 10 (Fig. 7C).

DISCUSSION

The findings of the present study demonstrate that seasonal obesity in male Syrian hamsters is eliminated by proximity to female hamsters or exposure to their volatile pheromonal signals. Female pheromones also reduce normal weight gain and promote episodic weight loss in SD-exposed males. This unusual resistance to weight gain is accomplished through anorexia and hyperactivity. To our knowledge, this is the first characterization of pheromone-induced anorexia (PIA).

We have found, consistent with the SD-induced onset of seasonal obesity, that SD-exposed male hamsters increase in body weight when they are pheromonally isolated from females. The absence of change in digging might suggest no change in food-seeking behavior (27), but familiarity with the location of the food hopper in the home cage may have masked a change in this behavior. Digging can also be associated with escape behavior (24); thus further investigation is warranted.
Self-grooming, a form of stress-coping behavior (19), is elevated in the obesity-resistant hamsters. Thus PIA may share some characteristics with human anorexia nervosa: 1) voluntary reduction of eating, 2) hyperactivity, 3) altered stress responsiveness, and 4) obsessive behavior (2, 39, 45). Consequently, PIA may provide a rare model of anorexia nervosa in a laboratory animal.

An obvious difference between PIA and anorexia nervosa is that PIA occurs in males only and anorexia nervosa occurs primarily in females. However, Syrian hamsters exhibit a number of other reverse sexual dimorphisms. In humans, rats, and mice, females exhibit larger adrenal glands, higher corticosteroid secretion, smaller body size, and less aggression (12, 21, 22, 29, 38, 48, 54). In Syrian hamsters, males exhibit these features (5, 9). Consequently, PIA may provide a rare model of anorexia nervosa in a laboratory animal.

Adiposity is reduced by gonadal steroids (11, 49). Although housing males in the same room as females may cause a slight delay in testicular atrophy (52), we have found in several experiments that, in the presence of females, SD-induced testicular atrophy becomes significant at 6 wk and remains maximal be-

![Graph](http://www.ajpendo.org)
of elevated corticosteroid secretion suggests PIA does not trigger endocrine stress responses.

Continuous exposure to volatile pheromonal signals of female hamsters is sufficient to suppress SD-induced weight gain for 18 wk. Interestingly, male responsiveness to female pheromones does not require previous physical contact with females. Thus the males do not associate female pheromones with a previous stressful event (i.e., attacks from nonreceptive females). The results also show that testicular activity remains low at this extended time point. Reversal of the suppression of body weight and testis weight confirms that day length is a critical factor in PIA and testicular regression. Testicular regression occurs independently of pheromonal condition, but PIA is dependent on female pheromones, and its reversal in their presence demonstrates synergistic interaction with SD exposure. In addition, the use of LD-exposed female hamsters as pheromone donors demonstrates that release of the suppressive signal does not require exposure of female hamsters to SDs. In this study, males in one experi-

**Fig. 6.** Effects of specific female pheromonal signals on seasonal energy conservation. **A:** group-housed males were sex-isolated, exposed to LDs or SDs, and treated for 10 wk with vehicle, bladder urine (BU), vaginal gland secretion (VGS), or water-extracted flank gland secretion (FGS_{H_2O}) collected from LD-exposed females. Data for vehicle-, BU-, and VGS-treated hamsters exposed to SDs were combined, as they did not differ significantly. Compared with LD/Vehicle treatment (n = 8), SD/Combined treatments (n = 24) elevated weight gain. Compared with LD/Vehicle treatment, SD/FGS_{H_2O} (n = 8) treatment did not alter weight gain significantly. **B:** sex-isolated males were individually housed, exposed to LDs or SDs for 5 wk, and treated for 12 wk with ethanol-extracted FGS (FGS_{EtOH}; n = 4). SD/FGS_{EtOH} treatment reduced food intake. **C** and **D:** individually housed males were exposed to LDs or SDs for 9 wk. Between weeks 1 and 6, males were sex isolated. Between weeks 6 and 9, 2 female hamsters subjected to flank glandectomy (FGX) were housed per room (n = 5). Compared with LD/FGX treatment, SD/FGX treatment did not reduce weight gain or food intake. Means ± SE are shown. For LD vs. SD comparison *P < 0.05 and **P < 0.01.
ment exhibited greater weight gain than males in other experiments. A strain difference, age, and group housing may have played a role in this difference. Nevertheless, exposure to females, their volatile pheromones, and their flank gland extracts promoted obesity resistance in all male hamsters.

Our experiments using specific pheromonal signals suggest that female flank glands are the source of the anorectic signal. Use of LD-exposed female hamsters as pheromone donors confirms that release of the suppressive signal does not require exposure of female hamsters to SDs. Relatively modest suppression of weight gain with FGSH\textsubscript{2}O treatment may indicate that the anorectic pheromonal signal is not highly water soluble. In addition, intermittent treatment may prevent full suppression of weight gain. FGSE\textsubscript{EtOH} treatment suppresses weight gain and eating in SD-exposed males. Moreover, surgical removal of flank glands from female hamsters eliminates suppressive effects of females on weight gain and eating in SD-exposed males.

The final experiment demonstrates that elevated dietary fat, which promotes hyperphagia, failed to do so during PIA. Although LD-exposed males exhibited transient hyperphagia, SD-exposed males became hypophagic after transfer from a low-fat diet to a moderate-fat diet in the presence of female hamsters. LD-exposed males exhibited a delay in the reduction of weight gain that is typical of hamsters in the socially separate condition (Morgan C and Urbanski HF, unpublished findings), and weight gain remained low in the final 6 wk of the experiment. In contrast, SD-exposed males reduced their food intake enough to remain normocaloric for several weeks before eventually becoming hypocaloric. These

**Fig. 7. Effects of elevated dietary fat on seasonal energy conservation.** Males were individually housed in sex-mixed rooms and exposed to LDs or SDs for 10 wk (n = 6). A: when LD/Mixed hamsters were transferred from low to moderate dietary fat, they exhibited no significant alteration of weight gain between weeks 1 and 3, followed by a reduction in weight gain at week 4. Low levels of weight gain persisted between weeks 4 and 10. Moderate dietary fat in SD/Mixed hamsters promoted reductions in weight gain from weeks 1 to 10. Between weeks 5 and 10, at least some hamsters in the SD/Mixed group lost weight. B: in LD/Mixed hamsters, transition from low to moderate dietary fat promoted hyperphagia for 3 wk followed by normophagia, except for hypophagia at week 6. Compared with LD/Mixed hamsters, moderate dietary fat in SD/Mixed hamsters reduced food intake from weeks 1 to 10 and promoted hypophagia between weeks 4 and 10. C: in LD/Mixed hamsters, moderate dietary fat promoted hypercaloric eating except for normocaloric eating at week 6. Compared with LD/Mixed hamsters, moderate dietary fat in SD/Mixed hamsters reduced caloric intake from weeks 1 to 10 and promoted hypercaloric intake at weeks 1 and 2. This was followed by normocaloric intake, except for hypocaloric intake at weeks 9 and 10. D: compared with LD/Mixed hamsters, moderate dietary fat in SD/Mixed hamsters reduced caloric efficiency. Means \pm SE are shown. For LD vs. SD comparison *P < 0.05 and **P < 0.01. AJP-Endocrinol Metab • VOL 285 • NOVEMBER 2003 • www.ajpendo.org
results demonstrate that PIA promotes robust obesity resistance by controlling caloric intake rather than just food intake.

Although it might appear to be maladaptive, PIA in male hamsters during SDs may promote survival of the species. Female Syrian hamsters are larger and fatter than males and consume more food to meet their energy demands (18). The females are highly aggressive toward adult males except on days of sexual receptivity, which occur during the LD breeding season (5, 14). Thus female hamsters exhibit social dominance over males. Because of their social dominance, it is likely that female hamsters limit male access to food in their natural habitat through aggressive encounters. If hungry hamsters are more aggressive in their pursuit of a meal, then PIA in males could further reduce male competitiveness for diminishing food supplies during SDs without energy-demanding aggressive encounters. Consistent with this view, female hamster weight gain and food intake are unaffected by proximity to males. Thus female hamsters may be more likely to survive when day length and food sources grow short in autumn and winter. Winter survival of a large number of females and a few hearty males would ensure generation of a large number of offspring in the following spring and summer.

Because PIA depends on seasonal changes in day length and male-female interactions, it is likely to play a critical role in hamster ethology. Moreover, this phenomenon may provide clues to understanding the behavior and physiology of eating, since it provides a novel model of anorexia. Models that rely on involuntary food deprivation can be used to identify compensatory mechanisms but cannot mimic the voluntary decrease in food intake that is characteristic of human anorexia nervosa. Surgical, genetic, and pharmacological methods can be used to identify components of pathways regulating food intake. The principal limitations of these models, however, are that surgical and genetic effects are not readily reversed and that pharmacological agents are typically used to study established pathways. Reduced food intake in PIA is voluntary and readily reversed by transferring males back from SDs to LDs, but underlying mechanisms are unknown. Therefore, investigation of this model may help to elucidate novel pathways controlling normal and disordered eating.

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DISCLOSURES

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