HUMORAL FACTORS CONTROLLING FOOD INTAKE IN DOGS

Lucille H. TURNER, Richard L. SOLOMON, Eliot STELLAR and Stanley N. WAMPLER

Department of Psychology, University of Pennsylvania
Philadelphia, Pennsylvania, USA

In his theoretical conception of the organization of the alimentary behavior system, Professor Konorski envisioned a complex neurological network, made up of excitatory and inhibitory mechanisms controlling hunger and satiety (Konorski and Gawroński 1970).

As Fig. 1 illustrates, the alimentary system includes (i) a food system (right side) which controls the eating of food from the moment it affects the sense organs until it is swallowed and (ii) a hunger system which provides the organism with the motivation to seek food when it is in a state of need (Konorski and Gawroński 1970, Fig. 3, p. 320).

The food system is responsive to the presence and absence of taste stimuli (unconditioned stimuli) as well as to the presence and absence of all conditioned stimuli for taste. The hunger (H) system interacts with the food (F) system and is directly responsive to humoral factors. In addition, the hunger (H) system is indirectly responsive to both unconditioned and conditioned stimuli, operating through sight and smell, the mouth, and sensory events in the rest of the alimentary tract during the processes of digestion and absorption.

All of these variables operate at the same time when a normal dog approaches food and eats. Therefore, during normal eating, variations in the hunger (H) system are confounded with variations in the food (F) system. To test the validity of Professor Konorski's theoretical model and, at the same time, to investigate the role of humoral factors in hunger and satiety, one strategy is to vary humoral factors controlling (H) without introducing correlated changes in those factors controlling (F).
We accomplished this by directly manipulating the nutrient content of the blood by means of chronic, intravenous infusion of dogs with either nutrient or non-nutrient fluids while measuring as the dependent variable their oral intake of standard food (a standard taste, texture, and nutritional value) during a limited meal period. In this way, we could alter the humoral influences on the hunger (H) and satiety (~H) mechanisms of the central nervous system independently of conditioned

Fig. 1. Professor Konorski’s conception of the organization of alimentary system. On the right is the food system which controls the consummatory phase from the moment food is in the mouth, until it is swallowed. FCSs are food conditioned stimuli affecting FCS receptors (in circle) and FCS central neural mechanisms (in square). F is the central neural response mechanism subject to the influence of T (taste) and conditioned food stimuli. Among other things, F controls salivation. A parallel system is envisioned for the absence of food (~FCS, ~F, and ~T). Note that ~F and F are mutually inhibitory. On the left is the hunger system which controls motivation and the appetitive phase. Sat. is the satiation mechanism responsive to humoral factors in the internal environment. Satiation receptors are shown in a circle and central mechanisms in a square. ΣHCS is the sum of the hunger conditioned stimuli, shown as receptors (circle) and central mechanisms (square). H represents a central “on-hunger” mechanism and ~H a central “off-hunger” mechanism which are mutually inhibitory. Excitatory influences are symbolized by arrowheads. Inhibitory influences are symbolized by perpendicular bars. Satiation inhibits both H and ~H. ΣHCS excites H and leads to the activation of the MBS (motor behavioral system), central (square) and peripheral response me-
and unconditioned stimuli arising in the mouth, gastric or absorptive mechanisms (F and ~F). The CSs and UCSs occurred only during the mealtime test periods, after the humoral events had already occurred.

Using the method of chronic intravenous infusion, we found that it took several days for intravenous feeding of nutrients to have a significant depressing effect on daily oral food intake. Similarly, it took several days after cessation of intravenous nutrients for depressed oral food intake to return to baseline. Thus, although there was regulation of food intake, it was sluggish and imprecise. These findings gave some support to the model in Fig. 1, because the model deduces the instigation of eating through the action of the food system (F and ~F), in the absence of any activity in the hunger (H) system.

**PROCEDURE**

Four pure-bred, female, beagle dogs were used in these experiments. Under a sterile surgical procedure described by Dudrick et al. (1968), a polyvinyl chloride catheter was threaded through the right jugular vein down to the right atrium of the heart. The animal was then fitted to a harness, which held a swivel connection for the external end of the catheter which made its exit through the back of the neck. External tubing, protected by a speedometer cable, was attached to the swivel connection and was then led out through the top of the cage, between the fingers of a variable-speed peristaltic pump to a sterile intravenous bottle suspended above the cage.

The experimental variables which we controlled were: (i) the fluid in the sterile, intravenous bottle, which was either diet or isotonic NaCl, and (ii) the speed of the peristaltic pump, which we set to control total liquid intravenous volume for 24 hr from a low of about 100 cm³ to a maximum of about 900 cm³. The sterile diet, supplied by Abbott, consisted of 20% glucose, 5% protein, and a mineral-vitamin mixture made up in 1 liter batches (see Dudrick et al. 1968). This mixture worked out to just about 1 cal/ml of diet.
Each animal was used as its own control. Each day, food was offered for a 30-min. period, with fresh water available. The food was commercially-sold canned KenL Ration, mixed with water so as to make a diet of 1 cal/g. Water was also available throughout the rest of the day. On each day, we recorded food intake, water intake, milliliters of intravenous infusion, body temperature and body weight, first under preoperative, baseline conditions, and later with the harness and cable in place. Then the surgery was performed, and the animal was returned to the home cage and was placed in the harness for isotonic saline infusion and postoperative baseline determinations. Finally, experimental infusions of nutrient were administered for periods of from 2 to 7 days, each period followed by additional control days of saline infusion.

RESULTS

The main results of our work can best be presented by individual cases. However, some uniformities are evident. (i) Over many months of measurement, all animals showed marked day-to-day fluctuations in food intake, but reached stable asymptotes of mean body weight and food intake during baseline conditions. (ii) During the infusion of nutrients calorically equal to, or greater than, the unsupplemented mean daily oral intake, oral food intake was significantly depressed but not eliminated. (iii) The depression of intake took 2–4 days before it reached its lower asymptote. (iv) During the intravenous nutrient infusion, and accompanying oral intake, all dogs overate, in the sense that they took in more calories than they did during baseline days, and thus they gained weight. (v) When infusion was changed from nutrient to saline it took 3–6 days before the oral food intake increased to baseline levels.

Dog 1

Cathy, a 7.0 kg, 8.5 month old dog, was used as a pilot animal, primarily to see whether chronic intravenous feeding of nutrients could inhibit oral food intake completely. Over three periods of 8–11 days of intravenous nutrients at the rate of 800–900 cal/day, oral intake of Burger Bit Pellets (ca. 4 cal/g) continued at about 200–250 cal/day, about one-third the usual daily intake of a dog this age and size. Toward the end of this period, Cathy developed an iron deficiency anemia and became terminally ill, so that the subsequent decline in her oral food intake could not be attributed to the intravenous nutrient. Iron deficiency was avoided in the other dogs by the addition of iron to the intravenous diet. In addition, the other dogs received the KenL Ration mixture rather than the Burger Bit Pellets.
Fig. 2. A: Preoperative baseline data on Freckles, showing daily food intake, water intake, temperature and body weight with and without the harness.
B: Postoperative data on Freckles, showing intravenous saline infusion and experimental manipulations (shaded areas) during which nutrients were infused.
Dog 2

Freckles, a 9.13 kg, 15 month old dog, was tested over a period of 200 days; 140 days are shown in Fig. 2. As the baseline data indicate, intake and body weight were quite stable over the period of adaptation to the harness and postoperatively when only saline was infused. Four separate test periods, when nutrients were infused, are shown in Fig. 2B and make it clear that oral intake was depressed but not eliminated during infusion. The depression took 2–3 days, and recovery of baseline intake during subsequent saline infusion took 3–6 days. During infusion of nutrients, total caloric intake exceeded baseline significantly, and body weight clearly rose throughout the nutrient infusion periods of the experiment.

Dog 3

Cassandra, a 7.70 kg, 15 month old dog, was an unoperated littermate control, tested at the same time as her sister, Freckles. She lived in an adjacent cage and was exposed to all of the events to which Freckles was exposed, except for the harness and intravenous infusion. Cassandra's data, covering Freckles' postoperative period, are shown in Fig. 3. Although there was the usual, high variability of oral intake from day to day, seen in all our animals, and a slight downward trend in average food intake, Cassandra’s data were very much like Freckles’ during the control, saline infusions — about 600 cal a day.

Fig. 3. Daily food intake of Cassandra, control animal for Freckles.
Dog 4

The data on Ginger, a 5.80 kg, 6 month old dog, are shown in Fig. 4. In five periods of intravenous infusion, Ginger showed increasing depression of oral intake over time and the slow recovery of baseline intake during subsequent saline infusion, as had Freckles. Again, total caloric intake, oral plus infusion, was elevated during nutrient infusion.

![Fig. 4. Food intake, water intake, temperature and body weight of Ginger, showing preoperative and postoperative baselines as well as periods of experimental manipulations (shaded areas) during which nutrients were infused.](image)

DISCUSSION

Our experiments show that, although the humoral factors in hunger and satiety are powerful, they operate slowly — during a time-frame of days — when they are manipulated by intravenous infusion of nutrients into the blood. Conversely, the conditioned and unconditioned stimuli provided by a standard food in a standard experimental setting are powerful enough to elicit some eating, even though the dog has been recently receiving an excess number of calories each day and, as a consequence, the dog gains weight.

In comparable experiments with intragastric feeding, usually as a preload just before a test meal, other investigators have shown that the stimuli to eat are usually powerful enough to elicit oral ingestion despite gastric distension and hyperalimentation. In puppies, Satinoff and Stanley (1963) showed that gastric preloads greatly in excess of
normal intake could not completely inhibit sucking and ingestion of milk. In adult dogs, Janowitz and Grossman (1963) showed that daily intragastric intubation of food over many months failed to eliminate oral intake, resulting in overeating and weight gain.

Quite clearly, our experiments provide further support for Professor Konorski's conceptualization of the organization of the alimentary behavior system and the neurological mechanism he envisioned in controlling hunger and satiety. A key role is properly given to the humoral factors in hunger, but these are slow-acting factors requiring several days to have full effect. On the short term, conditioned and unconditioned stimuli associated with oral intake play a strong enough role to elicit eating, even though intravenous hyperalimentation has resulted in overnourishment and weight gain. In Professor Konorski's terms, in a satiated dog the excitatory influence of the ~F subcenter upon the H subcenter will produce a burst of eating, provided that there has been the initial taste, smell, or sight of a good-tasting food. This burst of eating will cease when the ~F excitatory influence is just balanced by the inhibitory influence of the satiety (Sat) center on the H center. Our data show that this inhibitory influence can be rather weak relative to the ~F excitatory influence, even in presumably-satiated dogs.

This research was supported by USPHS Grant MH-04202 to Richard L. Solomon and USPHS Grant MH-15767 to Eliot Stellar. The authors are indebted to Dr Ezra Steiger, Resident in Surgery, for his instruction in this surgical procedure.

REFERENCES


Received 24 February 1975