REGULATION OF FOOD INTAKE

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Summary

The intake of foods is determined by physiological hunger, as well as psychological and cultural factors that modify the appetite. In animals, environmental temperature also affects food intake. Energy resources like glucose, lipids, amino acids, and also sodium all contribute to the regulation of food intake. Several other food components also have a role in the regulation of eating, but generally their mechanisms are much less well known. The regulation of eating is tuned by many neural and hormonal signals from the gastrointestinal tract, liver, adipose tissue, and from several parts of the brain. The hypothalamus has a key role in the regulation of food and fluid intakes, but higher levels of the brain, such as the cortical areas, are also involved in determining what people eat. In humans, psychosocial factors as well as cultural traditions have a great role in eating behaviors. Social and cultural pressures can favor eating and drinking to excess. Cafeteria-type fast foods lead to obesity in experimental animals as well as in humans. Two major problems in the proper regulation of food intake are the availability of energy-rich foods containing too little fiber (which are not diluted in volume and also lack volume stimuli) and a sedentary lifestyle (demanding a low energy consumption level). When people eat a high fiber vegan diet *ad libitum*, they lose weight. Apparently under these conditions, the regulation of food intake operates more correctly.

1. Introduction

While perhaps one in three people in the world is having problems in obtaining sufficient food, there are many who are obese. It is estimated that in the United States obesity is implicated in the deaths of 300 000 people annually from heart disease, stroke, diabetes, and cancer. The problem of increasing body weight is not limited to the United States or the European Union, but is also already visible in many other parts of the world such as China. The International Obesity Taskforce estimates that worldwide, 300 million people are obese. These figures make the topic of food intake regulation a very hot research issue. We know that some people are able to maintain their normal weight over decades while others are not. Some people show well-developed diet-induced thermogenesis (DIT): that is, metabolic burning of excessive energy-rich foods. On the other hand, we know that during fasting the consumption of energy decreases, and the results of losing weight in fasting are often meager. There are many mechanisms that contribute to food and drink intake.

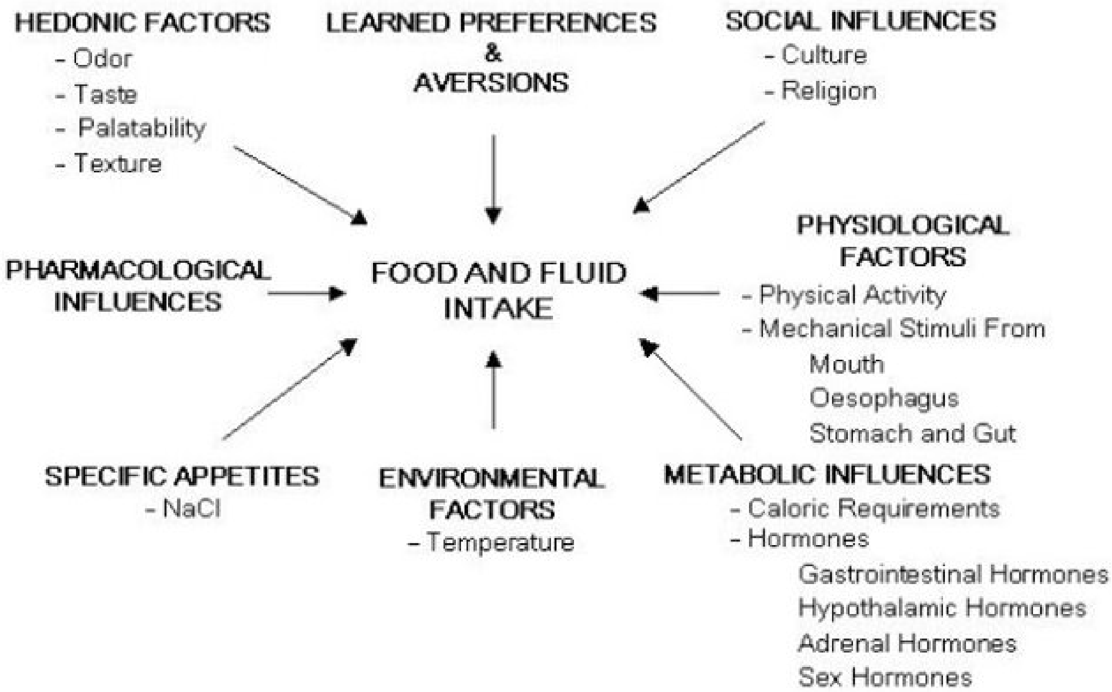

Figure 1. Some factors that determine food and fluid intake. Source: modified from Castonguay T.W. and Stern J.S. (1990). *Present Knowledge in Nutrition*, 6th edn (ed. M.L. Brown). 18 pp. Washington, D.C.: International Life Sciences Institute: Nutrition Foundation.

The food intake balance is sensed at several levels, and its regulation is also tuned to meet needs at several levels. The sensory organs and gastrointestinal tract *in toto*, as well as several other tissues sending humoral and neural messages, contribute to the control of food intake by the brain. The levels of several nutrients are monitored from the blood.

Eating and drinking are also important social activities. People eat and drink together for pleasure. Thus cultural aspects are major determinants of eating. In well-off countries, the marketing of foods is effective. There are many choices available, enabling us to select either nutritionally rich or nutritionally poor diets.

The word "appetite" (desire for food) is used to describe a mild hunger directed to certain food items. Hunger initiates food-selecting behavior and compels people to eat. Satiety stops us eating, although we can continue eating even when the satiety limit has been reached. Carbohydrates cause a feeling of being sated, but proteins and fats are a bit less effective in this regard.

Some ancient burial sites provide us with representations of contemporary human figures (for example, in Egypt), and practically all of these are lean. The ideal or appreciated body shape has, however, changed many times. Female Stone Age figurines indicate that adiposity was apparently esteemed in those days. We now know that this fertility symbol reflects the fact that sufficient fat stores are required for the hypothalamus–gonal axis to function. Now the fashion tends to be for slimness. One of first books on physiology was written purely about the physiology of taste (Brillat Savarin's *Physiologie du Gout*).

The hypothalamus is the center of food intake regulation, but the higher levels of the brain also contribute to the behavioral outcome.

Physical activity increases energy consumption and thus the need for food (see *Muscle Energy Metabolism*). Usually people in physical jobs eat more than those in light occupations. It has been proposed that a regulatory mechanism links physical activity and the desire to eat. Unfortunately, people in light jobs can eat more than they need. Perhaps there is a limit, above which physical activity has a significant effect on food intake, but below which it does not act to regulate it adequately. Another possibility is that the foods we have available at present have been processed to such a degree that the enriched energy content misleads our regulatory mechanisms. We have found that overweight people can lose weight rapidly (up to 20 kg within 3 months) when on a vegan diet of unprocessed foods, although they eat as much they like. Another explanation of this finding is that the bioavailability of the energy-rich food components is much lower, and they are lost because of increased gut function.

Animals can be divided into herbivores (eating principally plants), carnivores (eating mostly other animals), and omnivores (eating materials from both the plant and animal kingdoms). This indicates that there are genetically regulated mechanisms tailored to these diet choices, because all the species appear to manage well with their own diets. There are different human societies in which the members principally eat like all three groups of animals: that is, some are herbivores, some carnivores, and some omnivores. Humans are good in adapting to different diets. Indian and Japanese immigrants in the United States appear to have adopted the local diet, and may become obese.

At present, we know a lot about the regulation of the intake of energy-providing nutrients. Much less is known about the similar control of our input of minerals, vitamins, and similar compounds, which coexist in foods in low concentrations.

2. Sensory Signals and Food Intake

Foods give various signals from a distance: for instance smells attract animals and also humans, and the colors of fruits and berries indicate when the time is ripe to eat them. Chefs do their best to increase the appetite of restaurant customers, and cooks at home know how to attract the family to eat good food. Auditory signals can be strong determinants: Ivan Pavlov's experiments on conditioned reflexes with dogs are widely known.

Mechanoreceptors, osmoreceptors, and chemoreceptors collect signals in the gastrointestinal tract. Ingested food meets the receptors in the mouth and usually the receptors on the ceiling of the upper respiratory cavity. In the mouth, taste buds monitor five basic taste qualities: saltiness (salt), sourness (acid), sweetness (sugar), bitterness (a signal of danger), and "umami" (amino acids (glutamate)). These are all are important taste qualities of foods. We should not forget the sense of touch either: this enables us to sense food texture. Smell and texture provide signals that have a great effects on food intake in humans. The mouth, mucous membrane, and teeth are rich in receptors and in nerve endings. These receptors are also present on the way down the gastrointestinal tract.

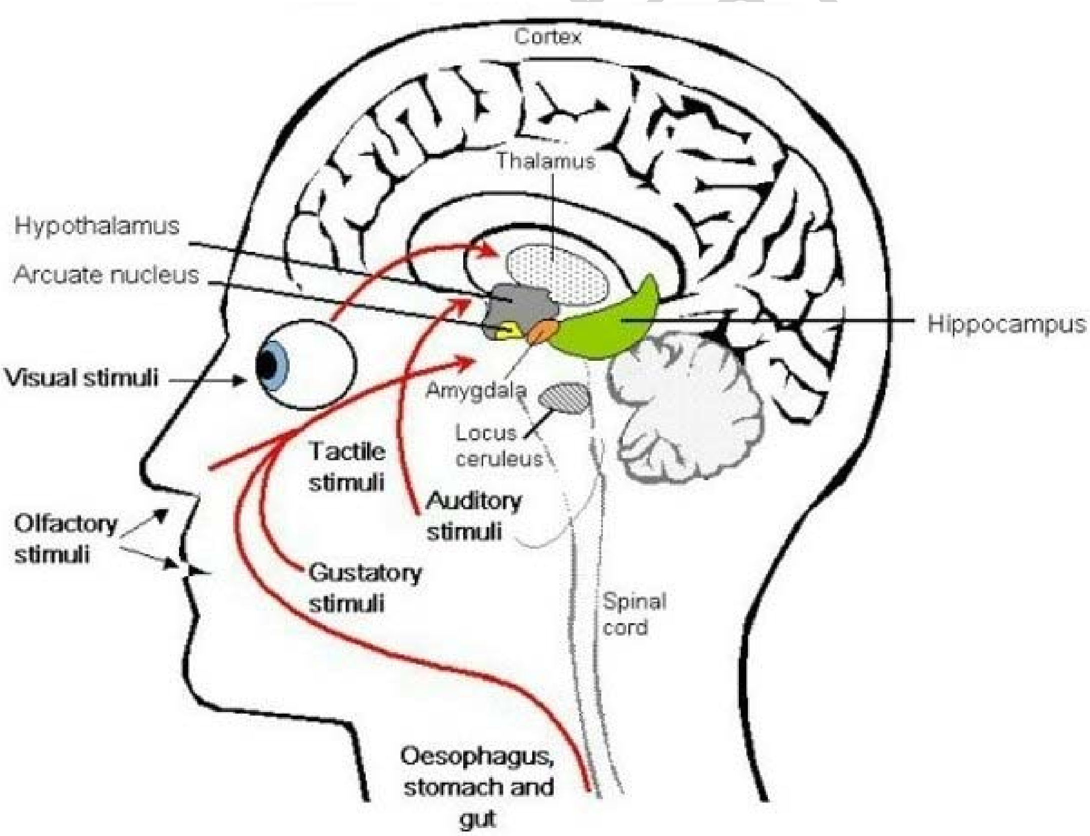

Figure 2. Different stimuli that contribute to the regulation of food and fluid intake in the hypothalamus

These sensory properties have significance not only in the selection of foods but also in determining satiety: that is, when sufficient food has been consumed. It has been shown that variation in the flavors of the food people are eating encourages them to eat larger quantities of certain food items, and this is even more so if a range of good foods is provided. Thus, the hedonistic properties of foods have an extensive effect on their consumption.

If cafeteria diets (that is, popular processed and "fast" foods) are given to rats, they become obese just as humans tend to do on this type of diet.

3. Gastrointestinal Neural Signals and Food Intake

Because the food components are spread over a large surface when the stomach and small intestine are digesting them, a lot of information can be gathered from mechanical as well as chemical sensing (see *Digestion*). By masticating chewing gum, one can temporarily postpone hunger. The tactile stimuli in the mouth contribute to this. In addition they cause a rich salivation, which leads to the swallowing of significant volumes of fluid, and thus to an increase in the gastric contents. The distension of the stomach results in a temporary feeling of satiety. At present, it is believed that an awareness that their stomach is full stops people eating. This may explain why people lose weight when they shift to an uncooked vegan diet containing a lot of fiber: their stomach fills quickly on this bulky food. A temporary loss of hunger can be achieved by placing a balloon in the stomach, which reduces the area available for ingested food. Drinking quantities of water, which also fills the stomach for a while, gives a similar response. The sensory signals travel via the vagus nerve to the hypothalamus. Because the vagus nerve also innervates a small area in the entrance of the ear, it is possible to stimulate it by, for example, attaching metal stimulators in the ear. These stimulators appear to be effective to some degree in the treatment of adiposity.

Eating produces sensory signals all over the upper gastrointestinal tract, and results in a cephalic thermogenic response. This increase of temperature coincides with an increase in plasma insulin, catecholamines, and glucagon. The vagal denervation of the pancreas blocks the initial release of insulin, and reduces the thermogenic response and norepinephrine release by 50%.

The rate of passing of food from the stomach to the duodenum is related to its composition. High lipid foods are pumped to the small intestine more slowly than are low lipid foods.

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Biographical Sketch

Dr Osmo Otto Päiviö Hänninen, DMS, Ph.D., Professor of Physiology, Chairman of the Department, University of Kuopio, Finland. was born in 1939 in Lahti, Finland. He studied at the University of Helsinki and the University of Turku, Finland, where he received his Master of Sciences (Biochemistry) in 1962, Licentiate of Medicine (MD) in 1964, Doctor of Medical Sciences (DMS) in 1966, and passed his dissertation in biochemistry for his Ph.D. in 1968. He has also studied genetics. He has been a specialist in sports medicine since 1986. He served as the research assistant of Professor K. Hartiala, 1962–1964; Assistant of Physiology, 1964–1965; Laborator of Physiology, 1966–1967; Docent of Physiology from 1967, and Associate Professor of Biochemistry, 1969–1971, at the University of Turku; Acting Professor in the Planning Office, 1971–1972; and from 1972, Professor of Physiology and Chairman of the Department of Physiology, University of Kuopio; Vice-President of the University of Kuopio, 1972–1979; and President, University of Kuopio, 1981–1984. Furthermore, he served as Visiting Professor of Physiology at Shanghai Medical University, China, 1991–1992, and at Sun Yat Sen Medical University, Guangzhou, China, 1998–1999; as Foreign Member of the Russian Academy of Natural Sciences, from 1994; and as Secretary General, International Council for Laboratory Animal Science, 1988–1995. He was the President of Societas Physiologica Finlandiae, 1990–1999, and has been President of the International Society for Pathophysiology and a Member of the Executive Committee since 1994, and the Treasurer of the International Union of Biological Sciences since 1997.

His special interests in research are biotransformation and adaptation to chemical loading, biomonitoring of toxicants, comparative biochemical toxicology, muscle metabolism and function, and ergonomics. He has contributed 266 papers in refereed journals and 72 in proceedings, and has written 55 reviews and 30 books or book chapters. He serves on the editorial board of four international journals and is at present the European Journal Editor of *Pathophysiology*.

Of his postgraduate students (32 in biotransformation, 27 in muscle metabolism and physiology, and five others), 12 serve as professors in china, finland, greece, sweden, and the united states.