Appetite 116 (2017) 277–283

Contents lists available at ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Lack of negative autocorrelations of daily food intake on successive days challenges the concept of the regulation of body weight in humans

David A. Levitsky*[1,2], Ji Eun Raea Limb[1], Lua Wilkinson[1], Anna Sewall[1], Yingyi Zhong[1], Ammar Olabi[3], Jean Hunter[4]

Division of Nutritional Sciences, Cornell University, Ithaca, NY 14853, USA

ARTICLE INFO

Article history:
Received 17 August 2016
Received in revised form
12 April 2017
Accepted 30 April 2017
Available online 5 May 2017

ABSTRACT

According to most theories, the amount of food consumed on one day should be negatively related to intake on subsequent days. Several studies have observed such a negative correlation between the amount consumed on one day and the amount consumed two to four days later. The present study attempted to replicate this observation by re-examining data from a previous study where all food ingested over a 30-day observation period was measured. Nine male and seven female participants received a vegan diet prepared, dispensed, and measured in a metabolic unit. Autocorrelations were performed on total food intake consume on one day and that consumed one to five days later. A significant positive correlation was detected between the weight of food eaten on one day and on the amount consumed on the following day (r = 0.29, 95% CI [0.37, 0.20]). No correlation was found between weights of food consumed on one day and up to twelve days later (r = 0.09, 95% CI [0.24, −0.06]), (r = 0.11, 95% CI [0.26, −0.0.26]) (r = 0.02, 95% CI [0.15, −0.7]) (r = −0.08, 95% CI [0.11, −0.09]). The same positive correlation with the previous day's intake was observed at the succeeding breakfast but not at either lunch or dinner. However, the participants underestimated their daily energy need resulting in a small, but statistically significant weight loss. Daily food intake increased slightly (13 g/day), but significantly, across the 30-day period. An analysis of the previous studies revealed that the negative correlations observed by others was caused by a statistical artifact resulting from normalizing data before testing for the correlations. These results, when combined with the published literature, indicate that there is little evidence that humans precisely compensate for the previous day's intake by altering the amount consumed on subsequent days. Moreover, the small but persistent increase in food intake suggests that physiological mechanisms that affect food intake operate more subtly and over much longer periods of time than the meal or even total daily intake.

1. Introduction

A fundamental premise of almost all theories of body weight is that body weight, or more precisely, body (fat) tissue, is regulated through the control of energy intake and energy expenditure.[5] Support for this premise is inferred from the observation that body weight of adults remains remarkably constant for long periods of time (Schwartz & Seeley, 1997). Any energetic error imposed such as a bout of overeating (e.g., holiday feast) or undereating (dieting) would be followed by a change in energy intake and/or expenditure, which would return body weight to its pre-perturbed state.

The first researchers to measure the accuracy to which energetic errors are corrected by changes in energy intake and/or expenditure were Gasnier and Mayer (Gasnier and Mayer, 1939a, b). They observed, in rabbits, an inverse relationship between energy

* Corresponding author.
E-mail address: dal4@cornell.edu (D.A. Levitsky).
[1] Division of Nutritional Sciences, Cornell University, Ithaca, NY 14850, USA.
[2] Department of Psychology, Cornell University, Ithaca, NY 14850, USA.
[3] American University of Beirut, Lebanon.
[4] Biological and Environmental Engineering, Cornell University, Ithaca, NY 14850, USA.

[5] Although the control of energy expenditure plays an important role in energy balance this article will restrict the discussion to the role of the control of energy intake.

http://dx.doi.org/10.1016/j.appet.2017.04.038
0195-6663/

expenditure on one day and energy intake on the next day. Edholm et al. (Edholm, Fletcher, Widdowson, & McCance, 1955) performed a similar study of the relationship between energy expenditure and energy intake in young soldiers where energy expenditure was measured by indirect calorimetry and energy intake by weighing before and after eating. Unlike the Gasnier and Mayer studies, they failed to observe a negative correlation between daily energy expenditure and energy intake consumed on that day and the next day, a finding repeatedly observed by others (Booyens & Mccance, 1957; Durnin, 1957, 1961; Edholm et al., 1970a). However, Edholm et al. (Edholm et al., 1955) did report that a negative correlation existed between energy expended on one day and energy intake consumed *two days* later.

Although others failed to replicate the observation between energy expenditure and energy intake measured two day later (Durnin, 1957, 1961; Edholm et al., 1970a), De Costa (de Castro, 1998), using self-reported dietary records, reported a similar negative correlation between the energy consumed on one day and the energy consumed two days later. While this intake-to-intake correlation is not as direct a test of the accuracy of energy balance (energy intake and energy expenditure), it still reflects physiological regulation. Overconsumption on one day is followed by underconsumption later, albeit two days later. However, de Costa relied on self-reported dietary records, a method that has serious flaws as a measure of energy intake (Schoeller, Bandini, & Dietz, 1990).

Using both dietary records and weighed food intake measures, Bray et al (Bray, Flatt, Volaufova, DeLany, & Champagne, 2008). findings supported De Costa's observation. They observed a negative correlation between the amount of energy consumed on one day and the amount consumed not two days later, but rather three to five days later. However, they only used on 7 days of observations. Champagne et al (Champagne et al., 2013). extended the period of observations in another sample to 17 days using the same methodology. They confirmed the apparent "corrective regulation" of their previous study (Bray et al., 2008) but rather than finding the compensation occurred between four to six days, they found compensation occurred 4, 8 and 9 days later but positive correlations occurring in intakes measured at 6 and 7 days later.

Because current theories of long-term regulation of human body weight depend upon the veracity of "corrective regulation" and studies published so far have yielded ambiguous results, we reexamined data collected from a study of human volunteers (Olabi et al., 2015) where total food intake was measured for 30 consecutive days.

2. Methods

2.1. Subjects

Sixteen volunteers, 9 females and 7 males, were recruited for a study of diet that will be used on a Mars space travel mission. Details are provided in a study reported by Olabi et al. (Olabi et al., 2015). They were non-vegetarians and did not have significant weight changes over a year. The subjects were staff and faculty members of Cornell University, ages ranging from 30 to 50 years. They were not receiving any medications or following a special diet, and did not dislike the foods they were going to be fed in the study. The study was approved by Cornell University Committee on Human Subjects; this secondary analysis study was reviewed by the Cornell Institutional Review Board.

The volunteers were informed that the purpose was to optimize the diet for astronauts by testing food products made of crops grown in a hydroponic environment. They were instructed to consume as much or as little of the food prepared by the staff.

The subject characteristics are shown in Table 1 below.

2.2. Foods

The foods consumed by the participants were prepared from a total vegan diet. Meat proteins were substituted with wheat and soy proteins. The subjects were provided with low calorie fruit flavored beverages, tea, coffee, and decaffeinated coffee at every meal and were free to add non-dairy creamer or non-caloric sweetener. Multivitamin and calcium supplements were provided to avoid vitamin deficiency.

All foods were freshly prepared or frozen/reheated, and met nutritional requirements. The 10-day rotation diet was repeated three times over the period of 30 days. The number of food items and types of food products provided at each meal and snacks is presented in Appendix A and B.

2.3. Procedures

The subjects were provided with three meals and two snacks each day. At every meal, food was available at the Frances A. Johnston and Charlotte M. Young Human Metabolic Research Unit at Cornell University. Food was offered at each meal from a buffet table to the participants. The participants were told to take as much or as little as they wanted. Food intake was measured by the staff at breakfast and lunch by weighing the amount of food put on their plate by the participant at the beginning of the meal and subtracting the amount of food left on the plate at the end of the meal. For dinner and weekend meals, subjects were provided with preweighed food in plastic containers. They were free to choose as many packaged food items as they desired and any leftover food was returned to the facility for measurement. All food items were stored in coolers with specific instruction to prepare the meals at home. The time when the foods were consumed was recorded by the participants.

2.4. Statistical analysis

Total daily food intake (g) of each subject was calculated by aggregating the amount of food consumed at the three meals and two snacks per day. Autocorrelations of the total daily food intake were calculated for each subject using a lag of between one to twelve days. The mean correlation for the 16 subjects were then calculated. The autocorrelations were repeated five times for each subject, each autocorrelation beginning on Day1, Day 2, Day 3, Day 4 and Day 5 of the study. The mean correlation coefficients and confidence interval was then determined for each of the five series of autocorrelations and a grand mean and confidence interval was then calculated. The alpha level for total daily correlations was set at 0.996 to compensate for repeated measures.

3. Results

Fig. 1 shows the mean total daily energy intake across the 30-day observation period. The average energy intake of the vegan diet was initially quite low, but increased gradually, yet significantly, across the time period (slope = 13.84 g/day, $p < 0.01$). This underestimation of daily intake to maintain energy balance is

Table 1
Original subject characteristics; mean ± SE.

	Total ($N = 16$)	Women ($N = 9$)	Men ($N = 7$)
Age (years)	43 ± 1.7	46.8 ± 1.3	38.1 ± 2.4
Height (cm)	171.4 ± 2.0	167.1 ± 2.5	176.8 ± 1.8
Weight (kg)	70.0 ± 2.9	69.0 ± 4.5	71.23 ± 3.5
BMI (kg/m^2)	23.9 ± 1.0	24.7 ± 1.5	22.8 ± 1.0