

Regulation of Human Energy Intake

Emily Dhurandhar, PhD

1/31/14 Energetics Course

Outline

- I. Evidence that energy intake is regulated
- II. Factors that influence energy intake
 - I. Physiological
 - II. Environmental
 - III. Food

Is Energy Intake Regulated?

Jean Mayer, 1955, describes three types of regulation:

1. Biometric Regulation: maximums and minimums defined by requirements and capacities of cells, organs, and systems.
2. Adaptation of energy intake to energy output.
3. Corrections in errors matching energy intake to output by successive recompensations.

Biometric Regulation

- Is there an upper limit to energy intake?

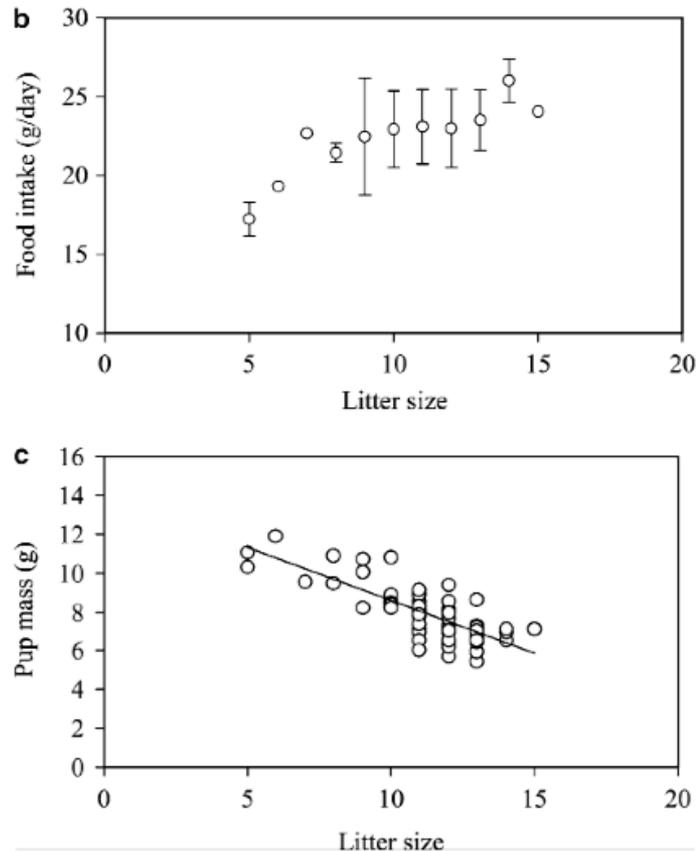


Fig. 2 a Relationship between mean food intake and day of reproduction for the MF1 mouse. Intake increases over days 1–10, but then reaches a plateau at days 10–18. b Asymptotic food intake (average over days 10–18) plotted against litter size. Bigger litters require greater energy demands, but for litters of more than ten the total intake is capped at 23 g per day. c Pup body mass at weaning in relation to litter size. In all cases $n = 71$ unmanipulated litters

Biometric Regulation

- Is there an upper limit to energy intake?
 - Tour de France Cyclists expend approximately 7,000 kcal/day and maintain energy balance.
 - Metabolic Scope for active wild animals ranges from 1.3 to 7.0 (Hammond & Diamond, Nature 1997).
 - Metabolic Scope = $SusMR/RMR$
 - Tour de France Athletes = 3.5-5.5 (Westerterp et al *J. Appl. Physiol.* 61, 2162–2167)

Does Energy Intake Reflect Energy Output?

In adult rats, increasing energy expenditure increases food intake to maintain body weight to a point.

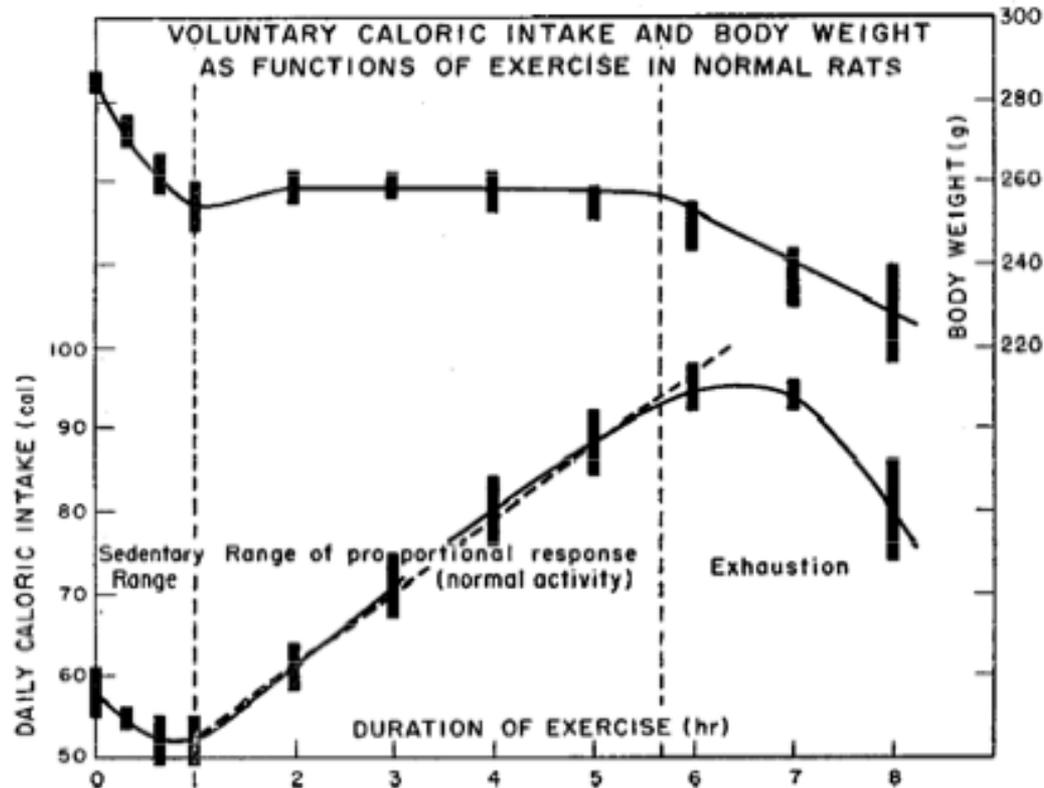


FIG. 2. Food intake and body weight as functions of duration of exercise in normal adult rats.

c

Does Energy Intake Reflect Energy Output?

Response to day-to-day variations in expenditure

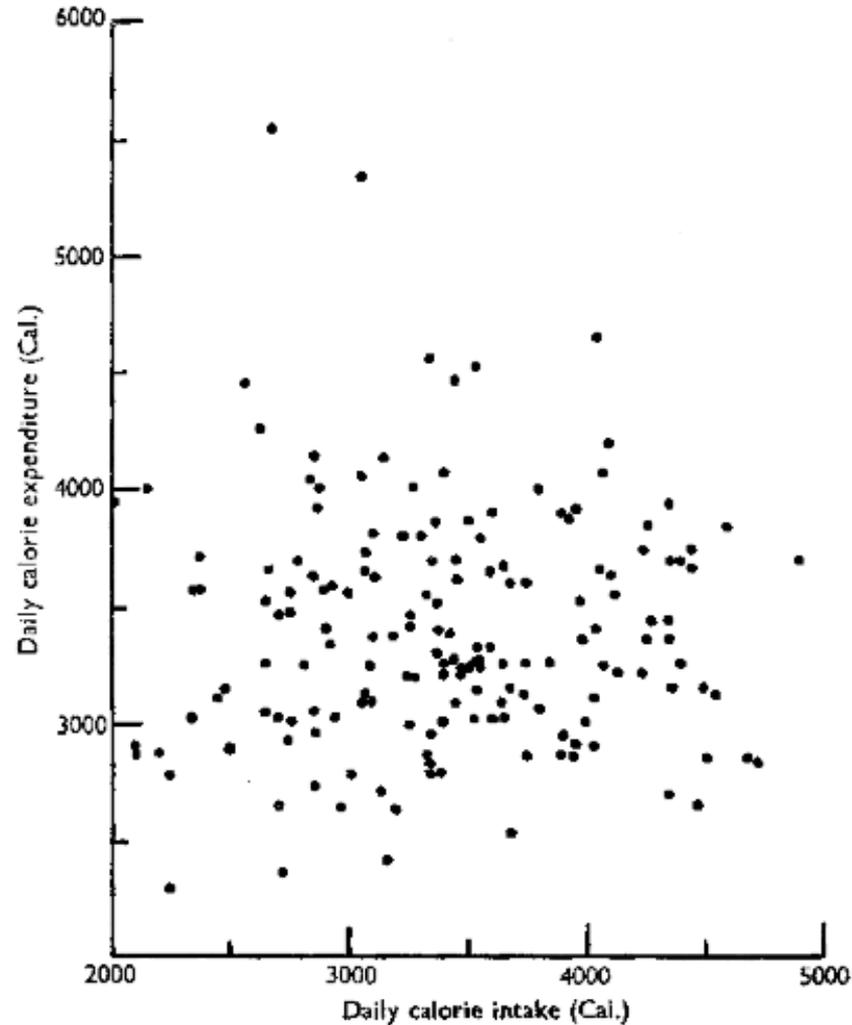


Fig. 2. Individual daily calorie intake and expenditure of the cadets. Daily individual food intake plotted against daily individual expenditure. Note the complete scatter of the results and the absence of any correlation.

Does Energy Intake Reflect Energy Output?

Response to day-to-day variations in expenditure

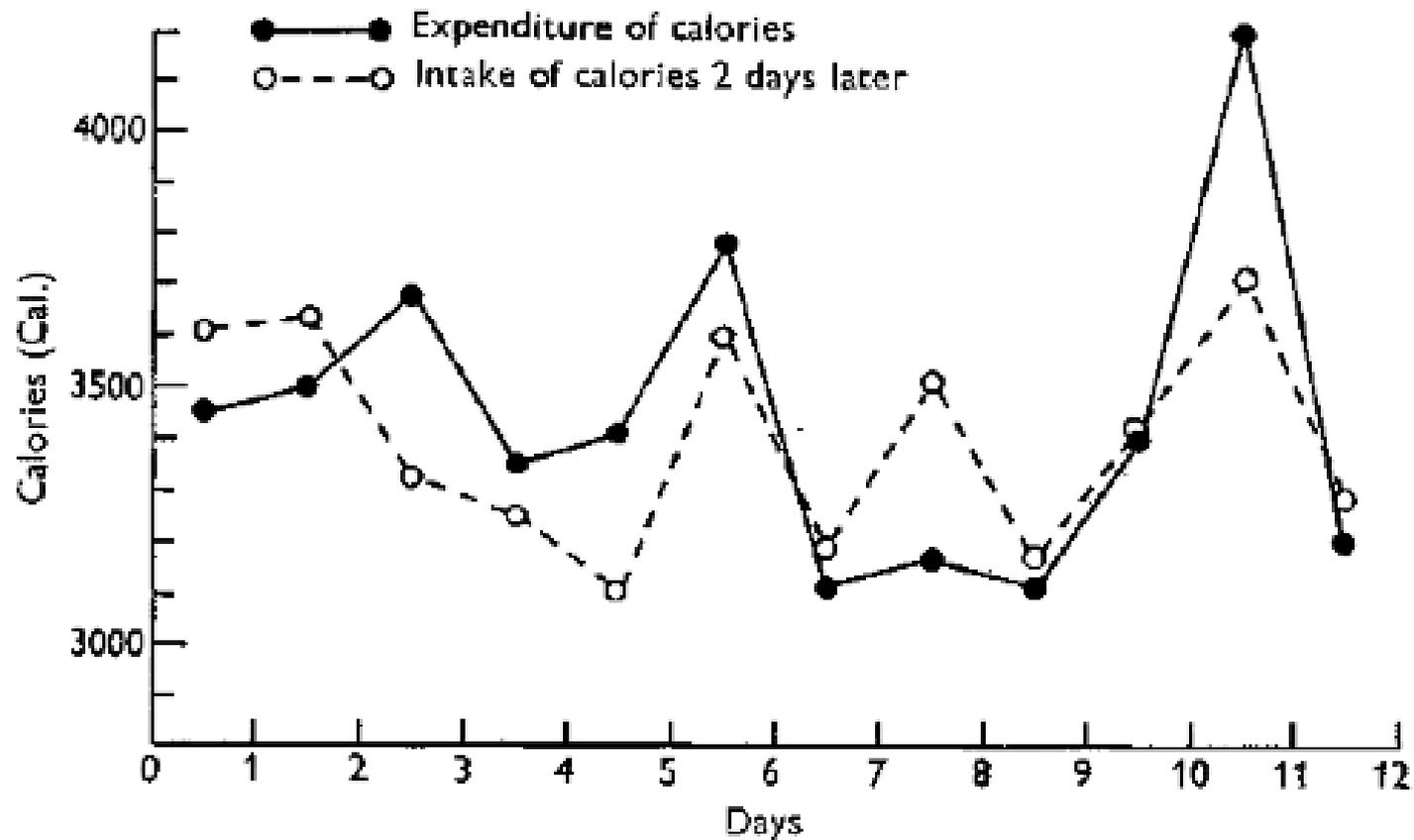


Fig. 3. Relationship between caloric expenditure and intake of the cadets. There is close agreement between the two plots indicating that daily intake of food is affected by the degree of activity 2 days previously.

Does Energy Intake Reflect Energy Output?

Response to exercise

Changes in *ad lib* energy intake over a few days of graded exercise in men & women.

Men- 9 days (Stubbs et al. EJCN. 2002. 56:129-140)

Exercise Energy Expenditure (MJ/Day)	Energy Intake (MJ/Day)	Energy Balance
0	11.6	-0.1
1.6	11.8	-1.0
3.2	11.8	-5.2

Women- 7 days (Int J Obes Relat Metab Disord **26**(6): 866-869)

Exercise Energy Expenditure (MJ/Day)	Energy Intake (MJ/Day)	Energy Balance
0	8.9	-1.3
1.9	9.2	-1.8
3.4	10.0	-2.9

Compensating during exercise regimen by increased EI, not decreased EE

- Sample: 54 middle-aged men with sedentary lifestyles (BMI: 28±3)
- Methods: Used synchronized accelerometry and heart rate to observe prescribed and non-prescribed PAEE during an 18-week exercise intervention, plus 2 week “detraining period”
- Results: No significant decrease in non-prescribed PAEE to compensate for prescribed PAEE
- Conclusion: Losing less weight than predicted by PAEE likely a result of increased energy intake (both groups were allowed to eat *ad libitum*)

PAEE differences between control and exercise groups, across time points

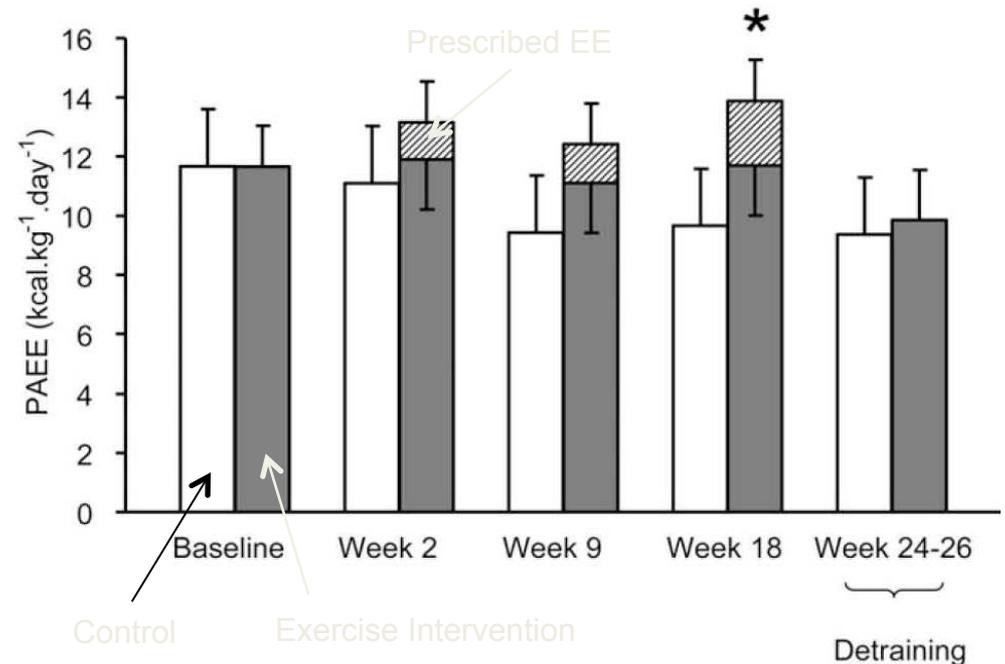


Figure 1. Physical activity energy expenditure (PAEE) throughout the study, no exercise group vs. prescribed exercise

Does Energy Intake Reflect Energy Output?

Response to exercise

Westerterp. Nutrition Reviews. 2010. 68(3):148-154.

“In conclusion, an exercise-induced increase in energy expenditure induces increased energy intake, thus compensating for the additional requirement, especially at higher exercise loads.”

Table 2 Exercise training and body weight in studies measuring total energy expenditure with doubly labeled water.

Reference	Subjects	Training mode	Δ Expenditure (MJ/d)	Δ Body weight (kg)
Bingham et al. (1989) ¹³	2 females, 3 males, normal weight	Jogging for 9 weeks	+2.8*	-0.9 ^{ns}
Blaak et al. (1992) ¹⁴	10 boys, obese	Cycling for 4 weeks	+1.3*	+0.5 ^{ns}
¹⁵	5 females, 8 males, normal weight	Jogging for 40 weeks	+2.3***	-0.9 ^{ns}
Westerterp et al. (1992) ¹⁶	12 males, normal weight	Weight training for 12 weeks	+0.8**	-1.1*

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$, for significant differences with baseline; ^{ns}, not statistically significant.

Does Energy Intake Reflect Energy Output?

Response to exercise

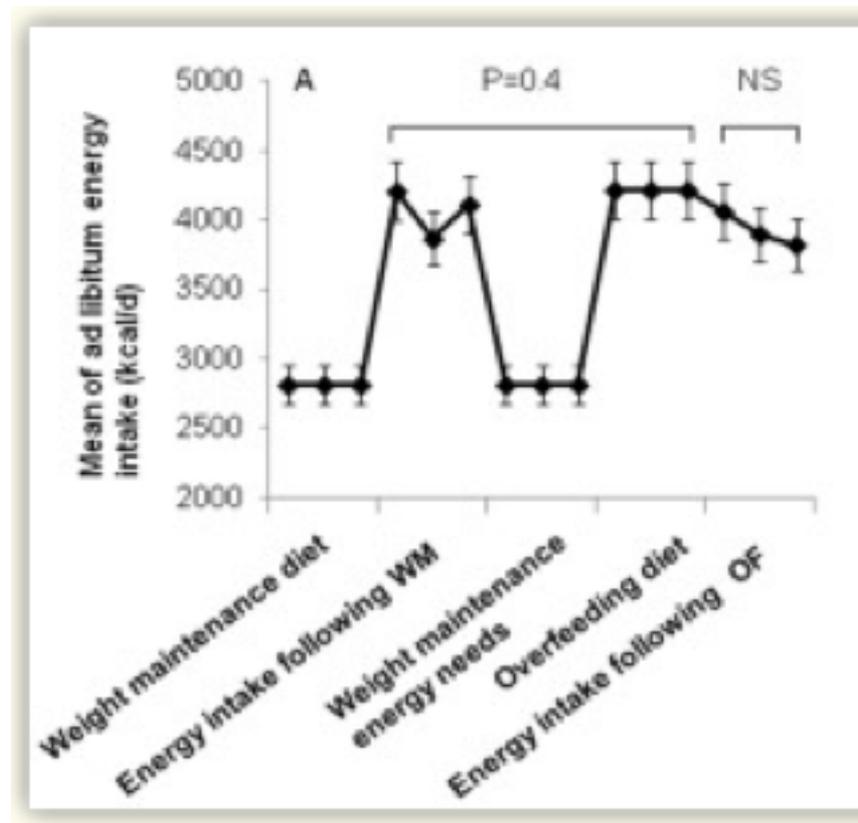
- Why do exercise studies not result in more weight loss? (Thomas et al. *Obes Rev.* 2012 Oct;13(10):835-47.)
 - Decrease in RMR, decrease in non-exercise energy expenditure, increase in lean mass, and increase in energy intake may all be responsible
 - Individuals training for a marathon increase energy intake (Westerterp et al. [Br J Nutr.](#) 1992 Jul;68(1):21-30.)

Evidence for Recovery from Errors in Energy Balance System

Recovery after overfeeding

Short-term studies looking for reduction in ad lib intake following overfeeding have mixed results.

-not long enough to produce substantial weight change



Evidence for Recovery from Errors in Energy Balance System

Recovery after overfeeding

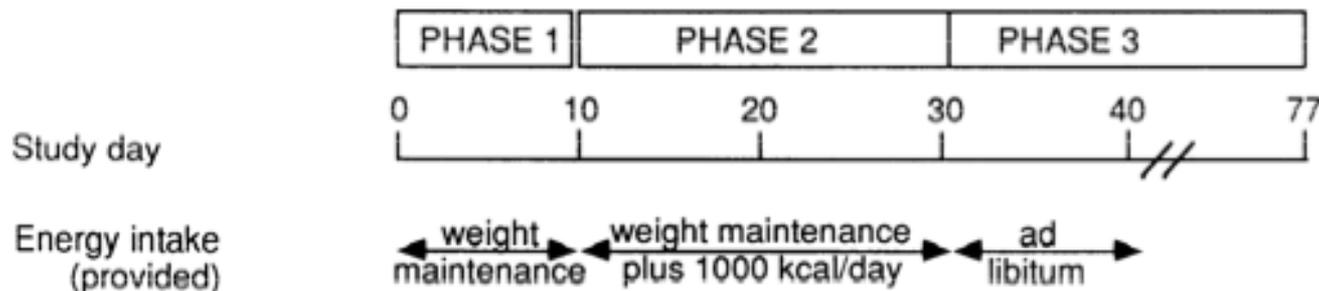


TABLE 2. Energy and nutrient intakes during weight maintenance (phase 1), overfeeding (phase 2), and 10 days after overfeeding (phase 3)

	Phase 1	Phase 2	Phase 3
Metabolizable energy, kJ/day	13,949±841	18,113±874‡	11,958±523*

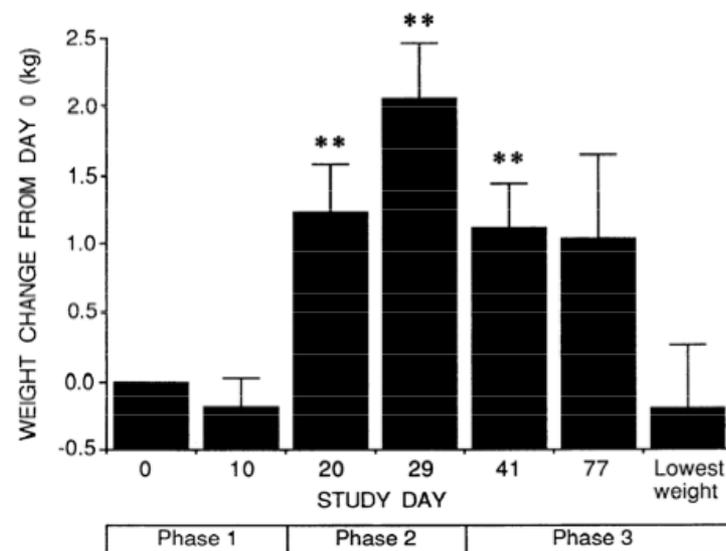
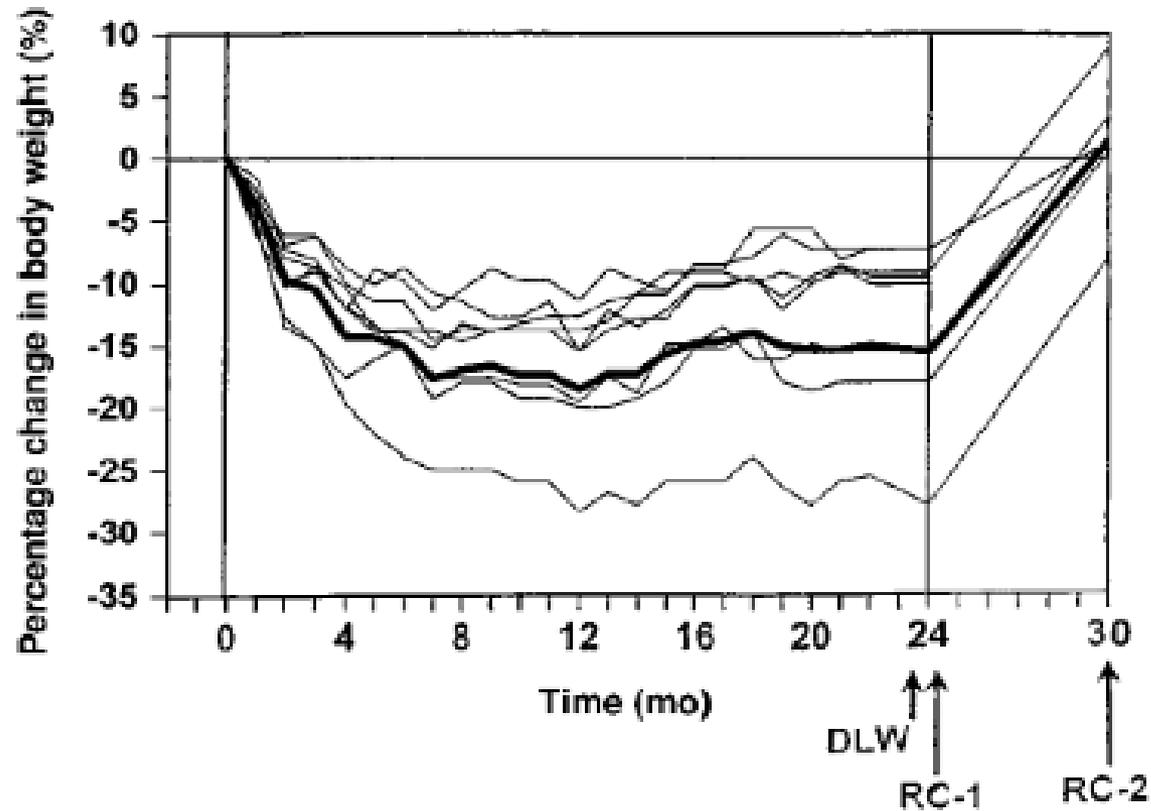


FIG. 2. Body weight change of subjects from study day 0. Values are means ± SE of data corrected for weight change between phases 1 and 2 (242 ± 115 g). ** $P < 0.01$ compared with values at start of overfeeding on study day 10.

Evidence for Recovery from Errors in Energy Balance System

Recovery after underfeeding

The Biosphere 2 experiment (Weyer et al. Am J Clin Nutr October 2000 vol. 72 no. 4 946-953)



Evidence for Recovery from Errors in Energy Balance System

Recovery after underfeeding

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TABLE 3

Physical characteristics of the control subjects and of the subgroup of 5 biospherians in whom 24-h energy metabolism was assessed in a respiratory chamber at within 1 wk and 6 mo after exit from Biosphere 2¹

	Control subjects (n = 89 M, 63 F)	Biospherians (n = 3 M, 2 F)	
		1 wk after exit	6 mo after exit
Age (y)	35.3 ± 16.0	43.6 ± 16.0	44.1 ± 16.0
Height (cm)	170 ± 8	171 ± 7	171 ± 7
Body weight (kg) ²	68.3 ± 8.7	59.7 ± 7.7 ³	68.5 ± 10.6
BMI (kg/m ²) ²	23.7 ± 3.4	19.8 ± 1.8 ³	22.9 ± 2.0
Percentage body fat (%) ⁴	21 ± 10	10 ± 3 ⁵	21 ± 2
24-h energy expenditure (kJ/d)	8120 ± 990	7360 ± 970 ⁶	7680 ± 1000
Sleeping metabolic rate (kJ/d)	5920 ± 730	5450 ± 520	5850 ± 720
Spontaneous physical activity (%)	7.5 ± 3.2	4.1 ± 1.3 ⁶	4.1 ± 1.2 ⁶
24-h Energy intake (kJ/d) ⁴	8100 ± 880	6810 ± 820 ³	8310 ± 1040
24-h Energy balance (kJ/d) ⁷	-20 ± 620	-550 ± 420	630 ± 370
24-h Respiratory quotient ^{7,8}	0.863 ± 0.027	0.951 ± 0.035 ⁵	0.888 ± 0.030

¹ $\bar{x} \pm \text{SD}$.

^{2,4,7}Significant time effect: ² $P < 0.001$, ⁴ $P < 0.01$, ⁷ $P < 0.05$.

^{3,5,6}Significantly different from control subjects after adjustment for age and sex: ³ $P < 0.01$, ⁵ $P < 0.001$, ⁶ $P < 0.05$.

⁸The 24-h respiratory quotient 1 wk after exit was measured under different dietary conditions (*see* Methods).

Is Energy Intake Regulated?

Summary

- There is a lower limit to energy intake.
- Theory and animal evidence supports an upper limit to energy intake.
- Energy intake is adjusted to output, but there is a time lag in response and output dose may matter.
- Correction for perturbations in energy balance by long-term successive compensations does occur.

Factors that influence energy intake: Physiological

- Glucostatic & Lipostatic Hypothesis
- Central Control of Intake
- Control of Meal Intake Through Signals from the G.I. Tract

Factors that influence energy intake: Physiological Glucostatic Theory

- One of the first theories to explain short-term regulation of food intake
- Proposed by Jean Mayer, 1955
- Based on four observations:
 1. Glucose required for nerve cell activity.
 2. Neurons with glucose receptors in hypothalamus are particularly active in hungry mice.
 3. Preferential use of carbohydrates as energy source in fed state.
 4. Low blood glucose associated with hunger, high blood glucose with meal cessation

Factors that influence energy intake: Physiological Lipostatic Theory

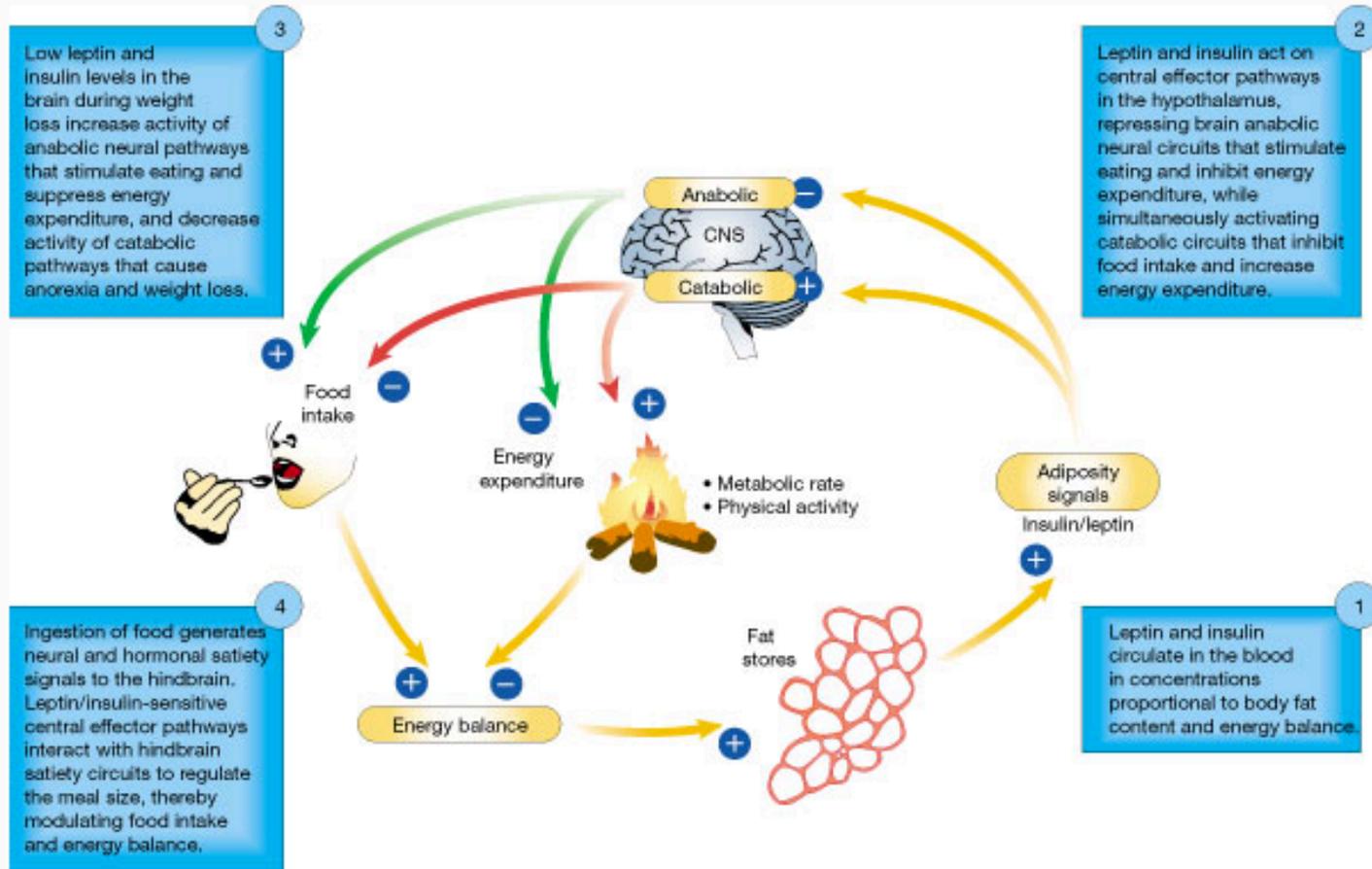
- One of the first theories to explain long-term regulation of food intake
- Proposed by Jean-Mayer, 1955
- Proposes that energy intake is regulated over the long-term by body fat stores

Factors that influence energy intake: Physiological Central Control of Food Intake

- The brain integrates many signals to regulate **feeding behavior** (reviewed in Morton et al. *Nature* **443**, 289-295 (21 September 2006))
 - Adiposity signals
 - Food reward
 - Signals from the G.I. Tract

Factors that influence energy intake: Physiological Central Control of Food Intake

Negative feedback from adipose tissue



Factors that influence energy intake: Physiological Central Control of Food Intake

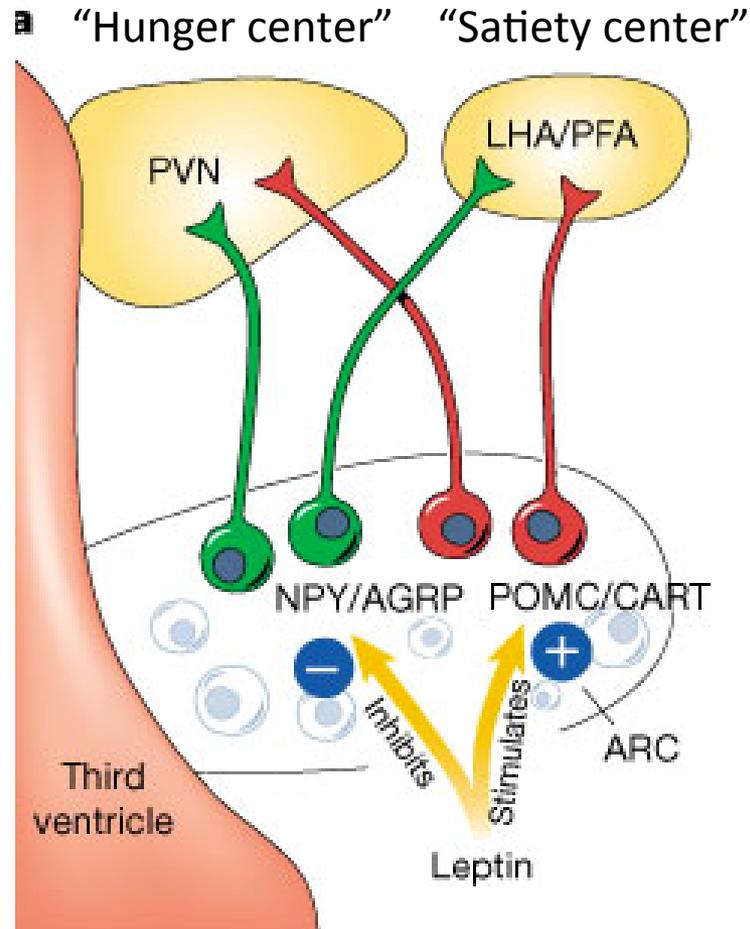
Negative feedback from adipose tissue

Table 1 Neuropeptides implicated in the control of energy homeostasis	
Molecule	Regulation by adiposity signals
Orexigenic	
NPY*	↓
AGRP*	↓
MCH	↓
Hypocretin 1 and 2/orexin A and B	↓
Galanin	?
Noradrenaline	?
Anorexigenic	
α-MSH*	↑
CRH*	↑
TRH*	↑
CART*	↑
IL-1β*	↑
Urocortin*	?
Glucagon-like peptide 1	?
Oxytocin	?
Neurotensin	?
Serotonin	?

Orexigenic refers to molecules that promote increased energy intake; anorexigenic implies the opposite. An asterisk designates documented, coordinated effects on both food intake and energy expenditure that promote a change in energy stores; arrows designate direction of effect exerted by one or both of the adiposity signals, leptin and insulin.

Factors that influence energy intake: Physiological Central Control of Food Intake

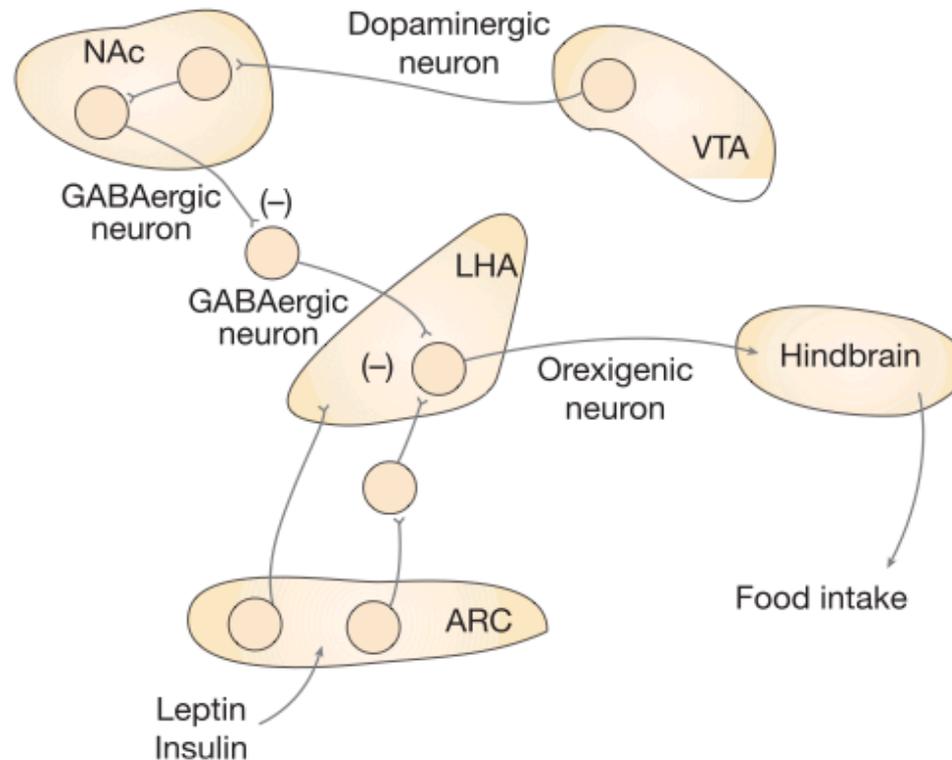
Negative feedback from adipose tissue



Factors that influence energy intake: Physiological Central Control of Food Intake

Food Reward

Perception of pleasure associated with consumption of a palatable food involves neuronal activation in the NAc and striatum, which through activation of opiate peptide receptors disinhibits the lateral hypothalamic area and thereby stimulates feeding.



Factors that influence energy intake: Physiological

The Role of Digestion and Gastrointestinal Factors in Controlling Meal Intake

Without feedback signals from the G.I. tract (sham feeding), meals are considerably larger.

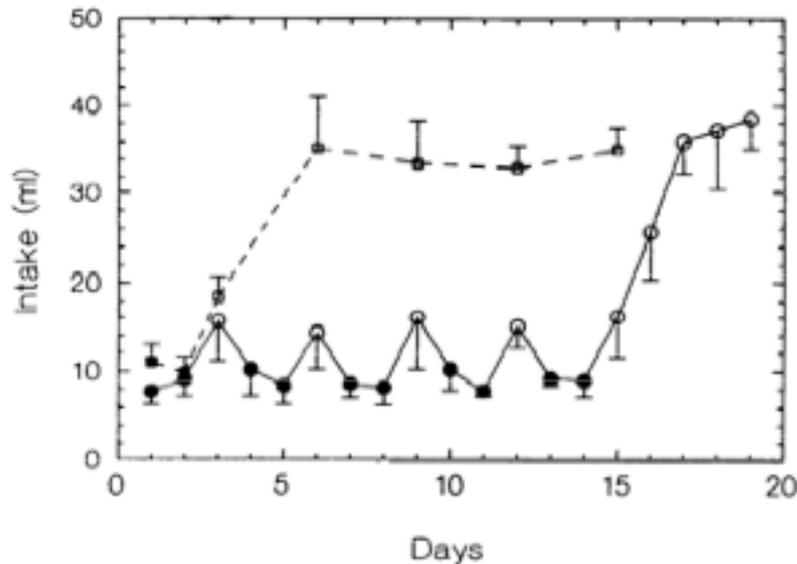


FIG. 1. Mean \pm SE 30-min intake for 2 groups on successive days of experiment. Closed symbols, days on which real-feeding tests were given; open symbols, days on which sham-feeding tests were given. Circles, RRS group; squares, SS group. SE bars are omitted on one side of average points to reduce clutter.

Factors that influence energy intake: Physiological

The Role of Digestion and Gastrointestinal Factors in Controlling Meal Intake

- Mechanical sensing from the enteric nervous system of digestive tract sends feedback to CNS food intake centers
- G.I. secretes hormones with receptors in the CNS that induce satiety and slow feeding
- Nutrient absorption sensed by CNS

Factors that influence energy intake: Physiological

The Role of Digestion and Gastrointestinal Factors in Controlling Meal Intake

Reduce Meal Size	Increase Meal Size
CCK	Ghrelin
Bombesin family	
Glucagon	
Glucagon-like-peptide-1	
Glucagon-like-peptide-2	
Apolipoprotein A-IV	
Amylin	
Somatostatin	
Enterostatin	
Peptide-YY-(3-36)	

Factors that influence energy intake: Physiological

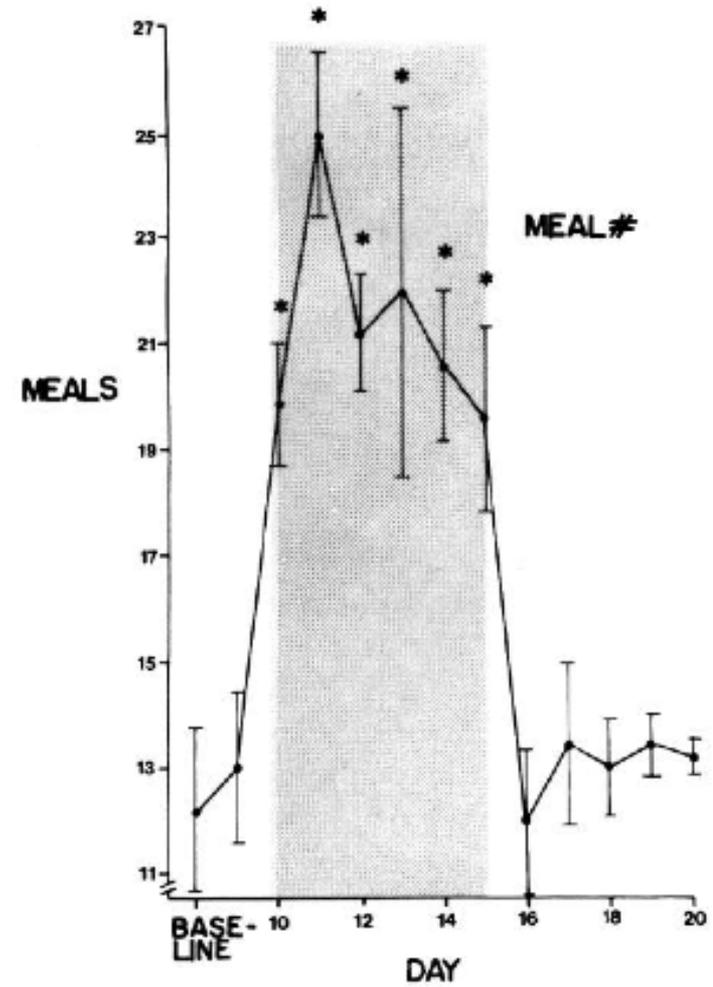
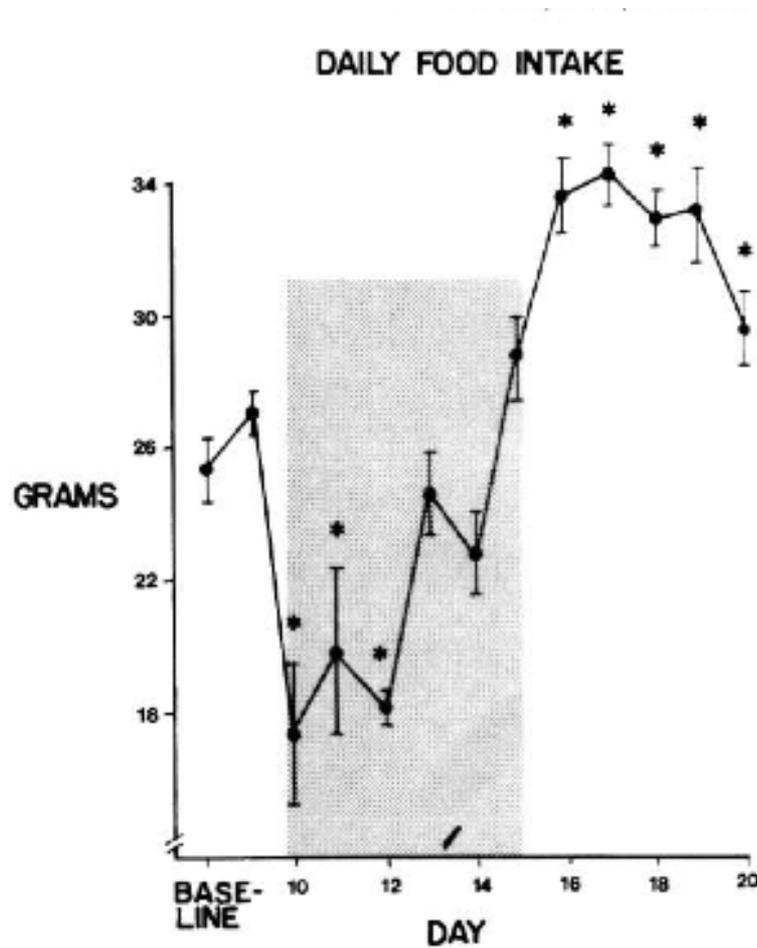
The Role of Digestion and Gastrointestinal Factors in Controlling Meal Intake

- Cholecystokinin (CCK)
 - Secreted from the duodenum in response to nutrients
 - Intravenous administration reduces meal size
 - CCK receptors on vagal nerve send signal to NTS in hindbrain

Factors that influence energy intake: Physiological

The Role of Digestion and Gastrointestinal Factors in Controlling Meal Intake

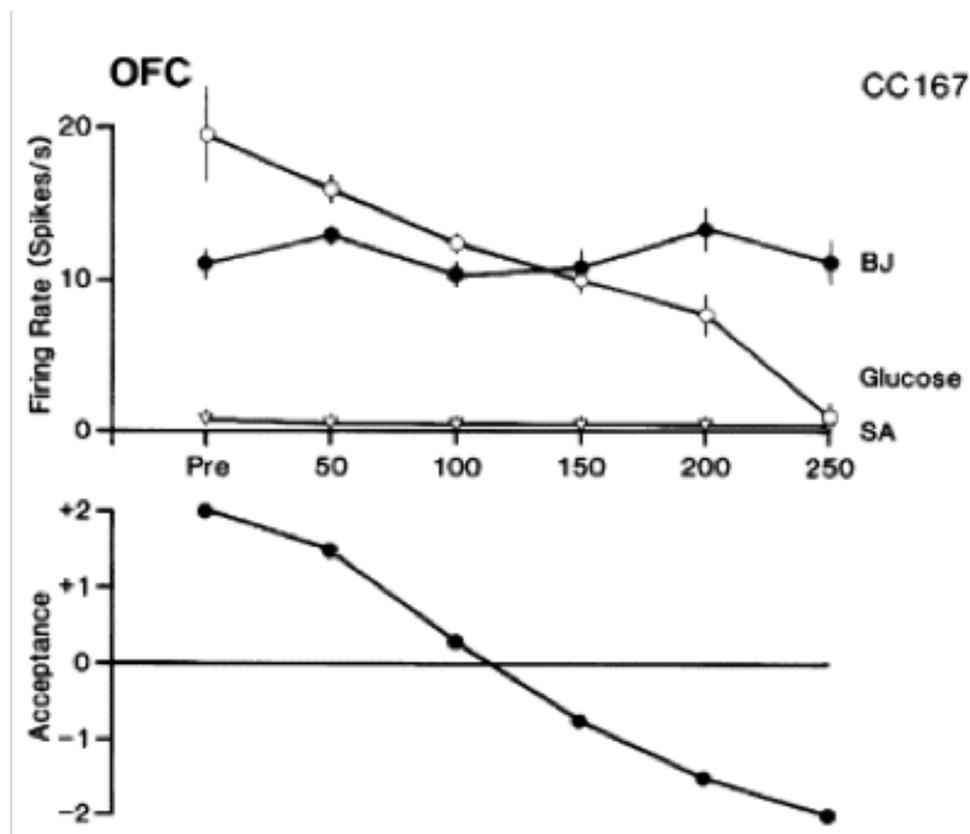
- If CCK reduces meal size, can it change overall energy intake and body weight? (West et al. Am J Physiol **246**(5 Pt 2): R776-787.)



Factors that influence energy intake: Physiological

The importance of oral, olfactory and visual cues

- Initiation of meal intake, motivation to continue eating
- Sensory specific satiety



Factors that influence energy intake: Physiological

The importance of taste, smell and sight

- Sensory Specific Satiety
- Eating a single food decreases food intake relative to eating a variety of foods

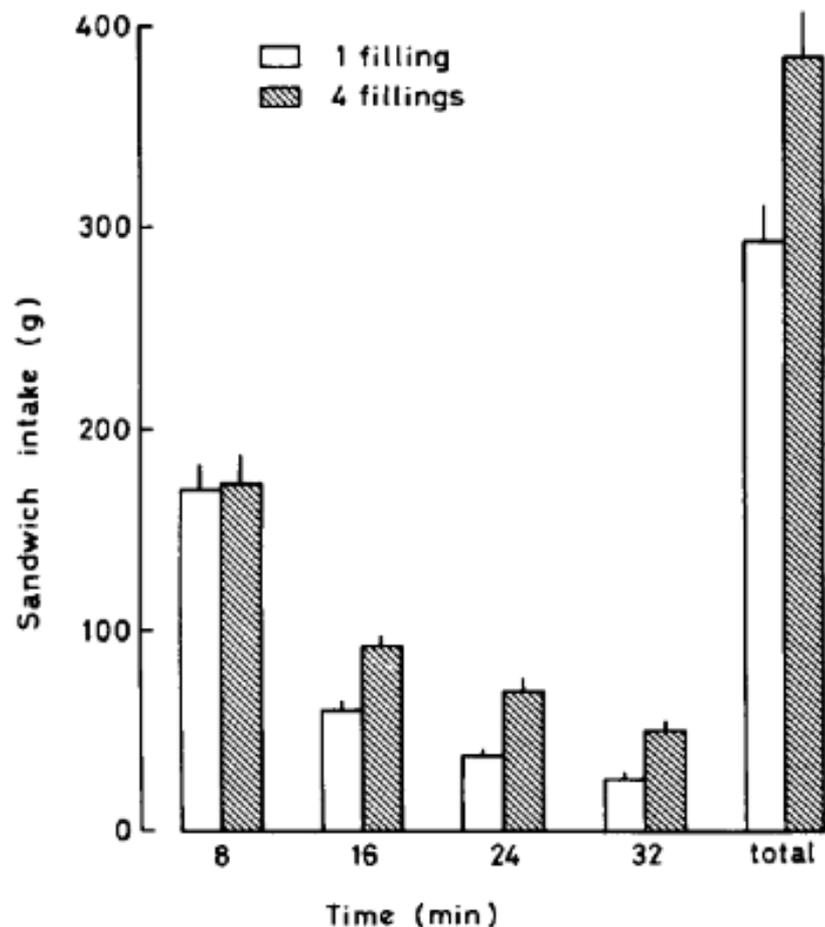


FIG. 1. Over 32 minutes 36 hungry students were offered either sandwiches with just one filling (either ham, egg, cheese, or tomato) or all four kinds of sandwiches in succession for eight minutes each. The mean (\pm S.E.M.) amounts eaten in each eight-minute course and over the whole test are shown. Subjects were tested twice, once in the 'variety' condition and once in a 'plain' condition.

Rolls et al. 1981. Physiol Behav **26**(2): 215-221.

Factors that influence energy intake: Physiological

The importance of taste, smell and sight

- Flavor-Nutrient Learning:
 - Flavor-nutrient hedonic learning: linking a flavor (Conditioned stimulus) with its postingestive effects (unconditioned stimulus)
 - Flavor-nutrient satiety learning: linking a flavor (conditioned stimulus) with its energy value (unconditioned stimulus)

Factors that influence energy intake: Physiological

The importance of taste, smell and sight

- Flavor-nutrient satiety learning (Booth et al. 1993. 53(1): 51–57)

Day 1	Day 2	Day 3	Day 4
25% CHO both grape and orange	10% CHO (1/2 grape, 1/2 orange) OR 45% CHO (1/2 grape, 1/2 orange)	10% CHO (1/2 grape, 1/2 orange) OR 45% CHO (1/2 grape, 1/2 orange)	25% CHO both grape and orange

Trained with
orange

Intake
reflects
chow
intake

Intake reflects
chow intake

Intake of 10%
increases, Intake of
45% increases

If trained with 10%
CHO increased
intake of orange
flavor, If trained
with 45%
decreased intake of
orange

Trained with
grape

Intake
reflects
chow
intake

Intake reflects
chow intake

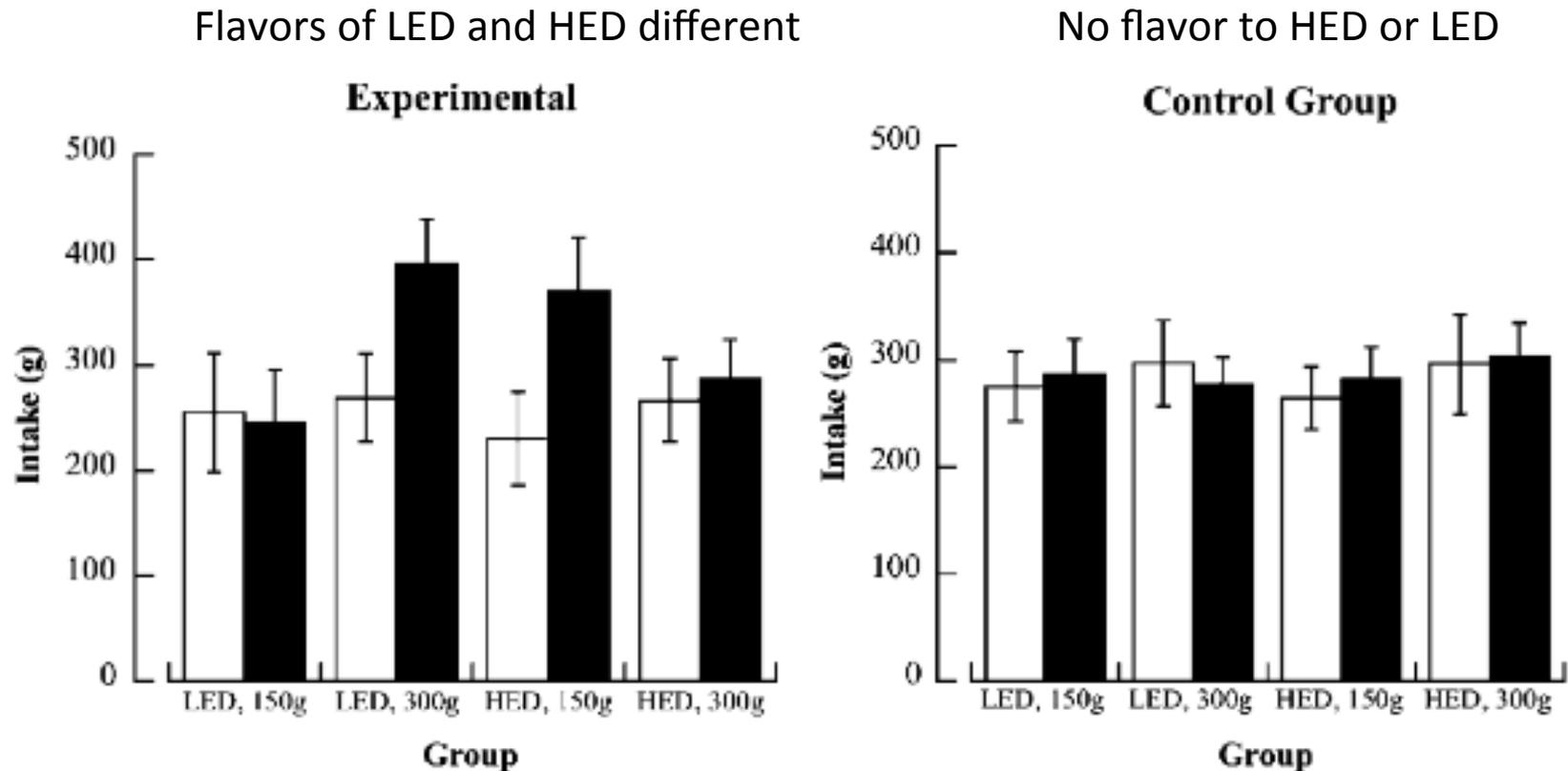
Intake of 10%
increases, Intake of
45% increases

If trained with 10%
CHO increased intake
of grape flavor, If
trained with 45%
decreased intake of
grape

Factors that influence energy intake: Physiological

The importance of taste, smell and sight

Flavor-nutrient satiety learning: flavor is crucial



Open bars before training, filled bars after training

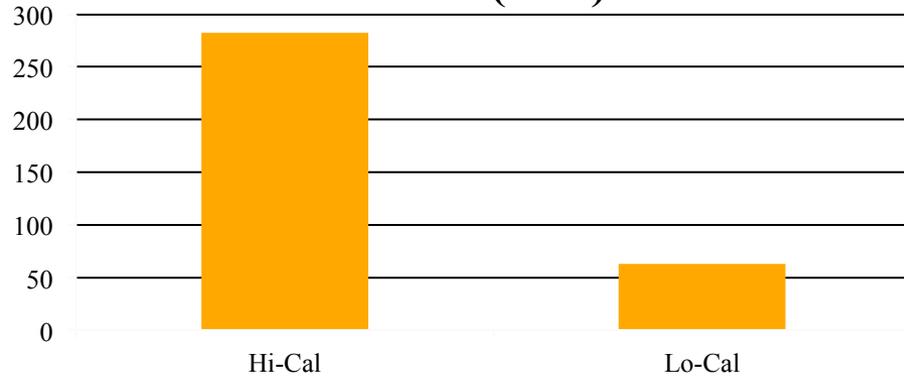
Yeomans et al. 2009. *Appetite* 52(2): 469-478.

Factors that influence energy intake: Physiological

The importance of taste, smell and sight

Implications of learned flavor-nutrient satiation for low calorie foods

Snack (kcal)



Appetite, 1989, 12, 95–103

Learned Caloric Adjustment of Human Intake

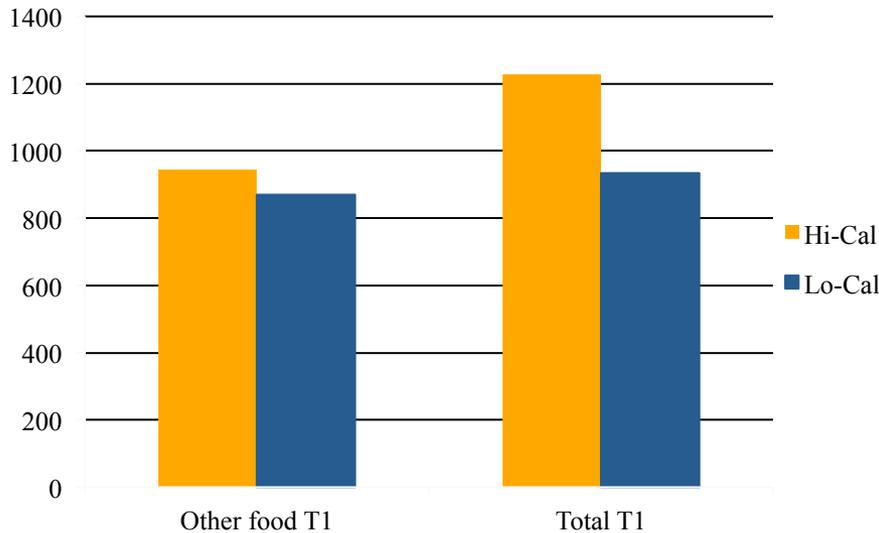
JEANINE LOUIS-SYLVESTRE, ALAIN TOURNIER,
PHILIPPE VERGER, MICHÈLE CHABERT and
BRIGITTE DELORME

Laboratoire de Neurobiologie de la Nutrition E.P.H.E., Université Paris 6

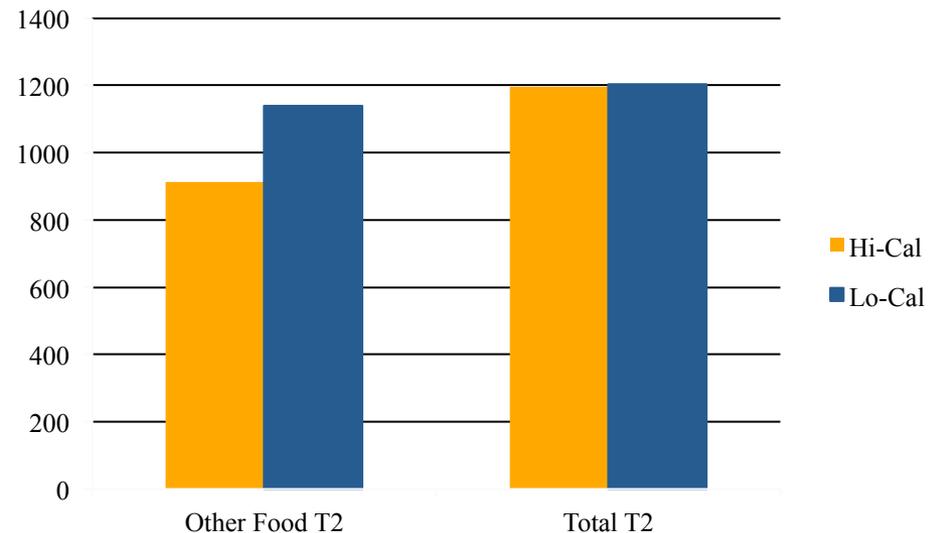
JOSEPH HOSSENLOPP

Ecole Nationale des Sciences de l'Industrie Alimentaire

Day 1



After 4 days of consumption

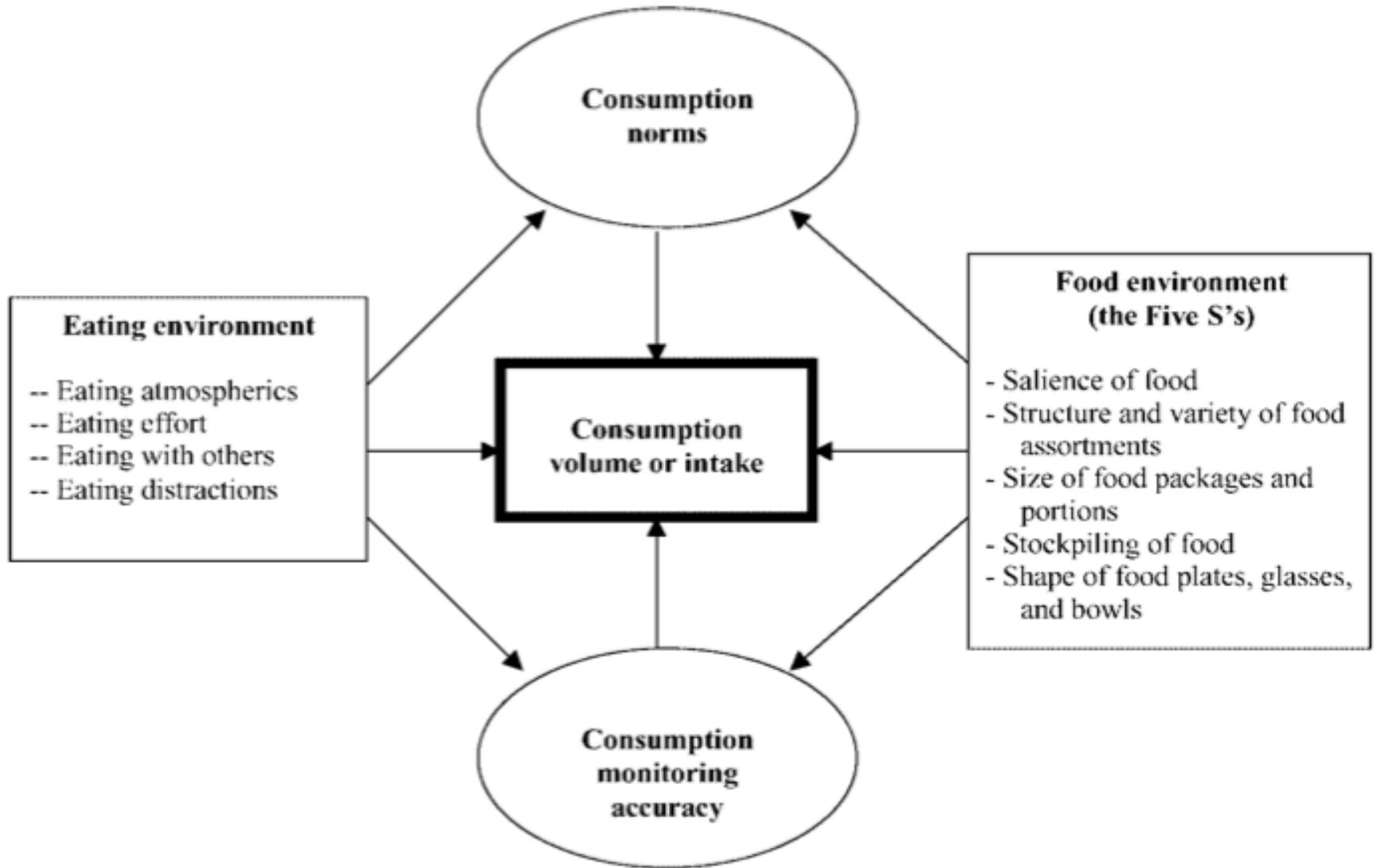


Factors That Regulate Energy Intake: Physiological

Summary

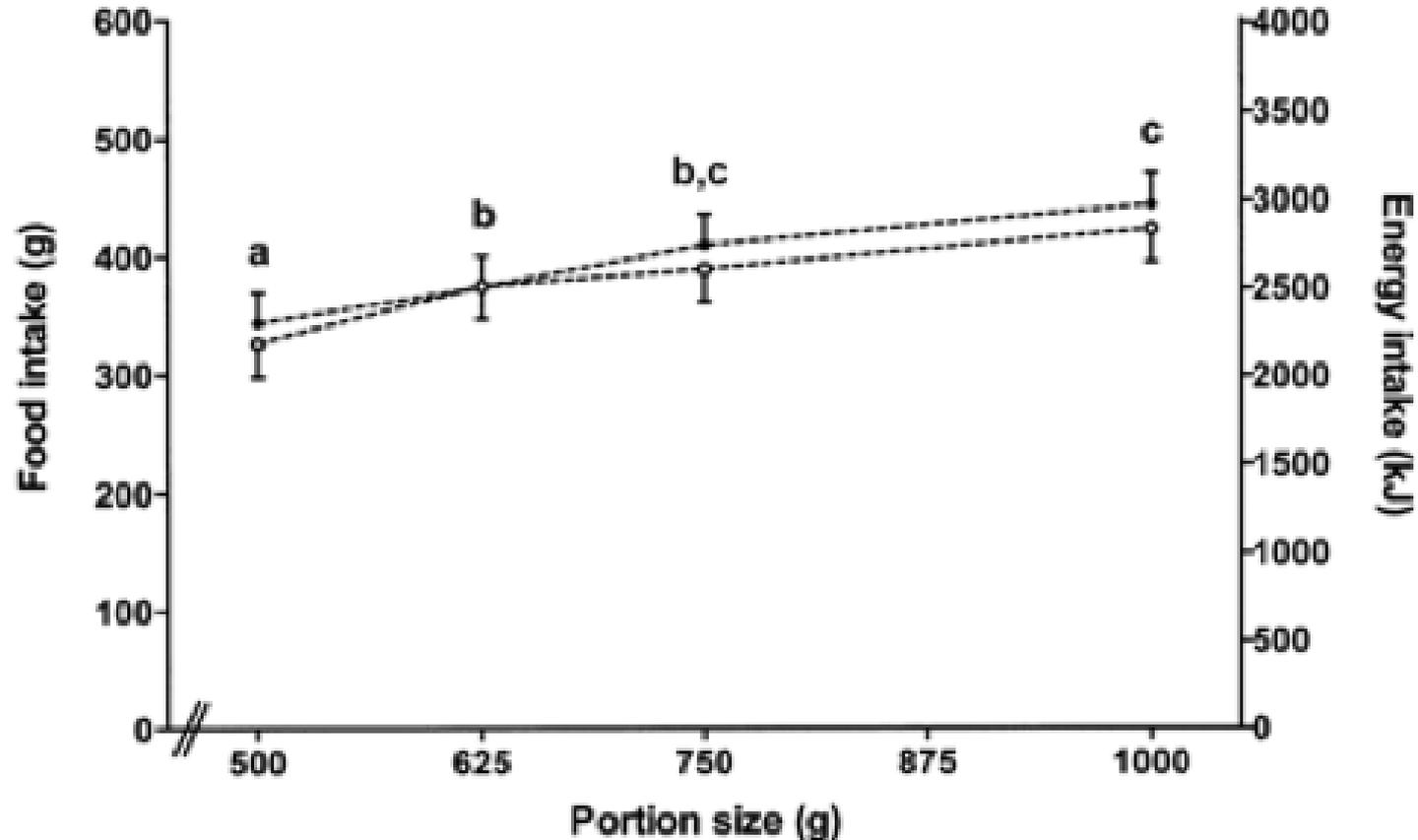
- The physiological system that regulate energy intake is complex and has many redundant pathways.
- Nutrients play a critical role in stimulating this system, and their effects on energy stores are likely mediated by it.
- Learning mechanisms are in place to link the flavor of a food with its energy content.
- The systems that regulate longterm energy intake are distinct from those that regulate meal intake, but the two systems talk to each other.

Factors that influence energy intake: Environmental



Factors that influence energy intake: Environmental Portion Sizes

A 30% (161 kcal) increase in intake occurred between the largest and smallest portion.



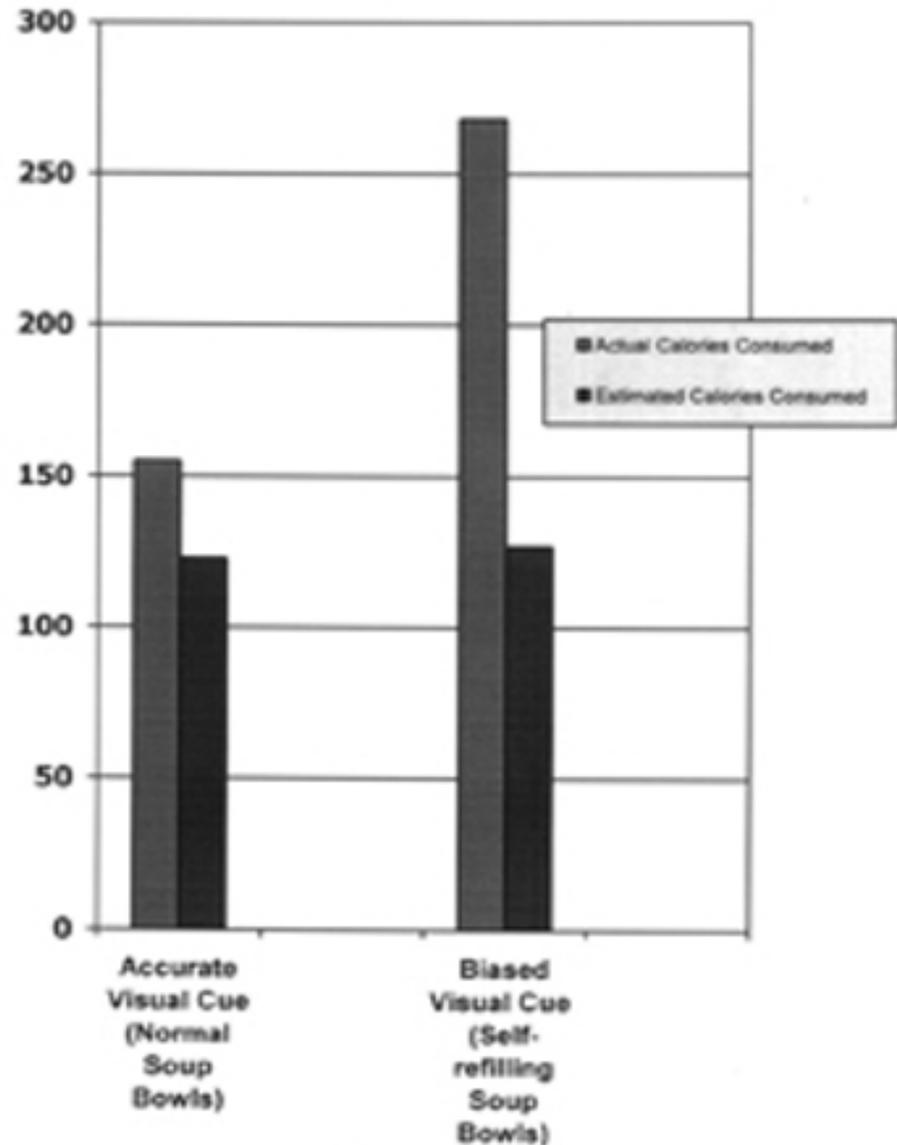
Open circles = serving dish with plate,
closed circles = plate only

Factors that influence energy intake: Environmental Visual Cues & Estimation of Portion Sizes

- Plate, bowl, or glass size:
 - Serves as an anchor for judging portion size
 - Smaller plate sizes mean less food is taken and consumed without the perception of less (Wansink et al. J Exp Psychol Appl. 2013 Dec; 19(4):320-32)
 - Height of fill of a glass is reference- tall, thin glass with the same amount of liquid as a short, stout glass will be perceived to contain more liquid (Wansink. Annu. Rev. Nutr. 2004. 24:455–79)

Factors that influence energy intake: Environmental Visual Cues & Estimation of Portion Sizes

“Bottomless”
bowls increase
soup intake, but
not perceived
soup intake.



Wansink et al. 2012. Obesity
Research [Volume 13, Issue 1](#), pages
93-100.

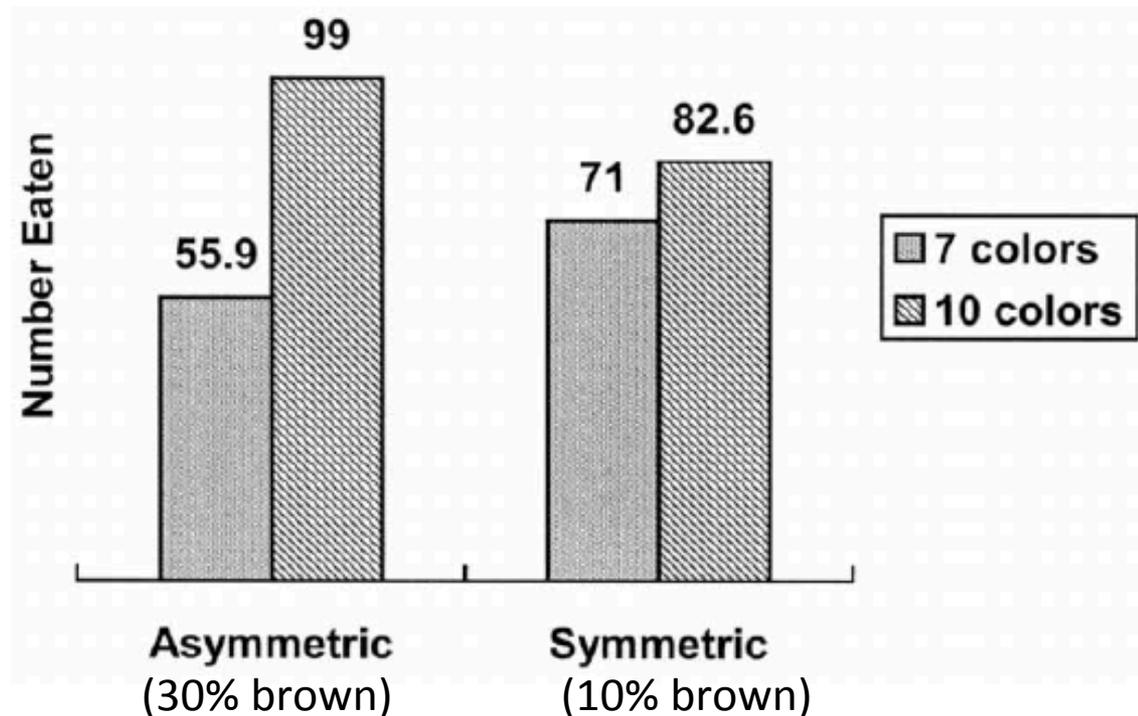
Factors that influence energy intake: Environmental

Temperature, lighting, odors, social factors

- Cold environments increase energy intake
- Bright, harsh lighting decreases intake; soft lighting increases it
- Odors have quick sensory specific satiety, but can initiate eating episodes

Factors that influence energy intake: Environmental Variety and choice structure

The *perception* of variety is sufficient to increase intake (M&M's test the same, but increasing color variety increases consumption).



Factors that influence energy intake: Environmental Variety and choice structure

- Consistent exposure to variety increases energy intake and weight gain in rats
- Effect wears off for a single set of food options; new varieties must be introduced to produce consistent increases in EI
- (Le Magnen J. Hunger. Cambridge (UK): Cambridge Univ. Press; 1985.)

Factors that influence energy intake: Environmental Effort

- In-shell pistachios reduce consumption by 86 kcal (41%) compared to shelled nuts during an ad libitum snack. (Honselman CS. *Appetite*. 2011 Oct;57(2):414-7.)

Factors that influence energy intake: Environmental

Preordering

Avoiding environmental cues that stimulate intake may reduce “unhealthy” choices

Table. Preordering Nearly Doubles the Selection of Healthy Entrées^a

	%		Change	Odds Ratio (95% CI)
	Preordered Entrée in the Morning	Purchased Entrée at Lunchtime		
Selected a healthy entrée	29.4	15.3	-48.0	0.55 (0.35-0.86)
Selected a less healthy entrée	70.8	85.7	21.0	1.81 (1.14-2.87)

^a N = 2422. Results are based on a mixed-effects logistic regression where students were nested within grades. Dependent variables were healthy entrée and less healthy entrée. Healthy and less healthy entrées were determined using a nutrient-based method.

From: **Preordering School Lunch Encourages Better Food Choices by Children**

JAMA Pediatr. 2013;167(7):673-674. doi:10.1001/jamapediatrics.2013.82

Factors That Regulate Energy Intake: Environmental

Summary

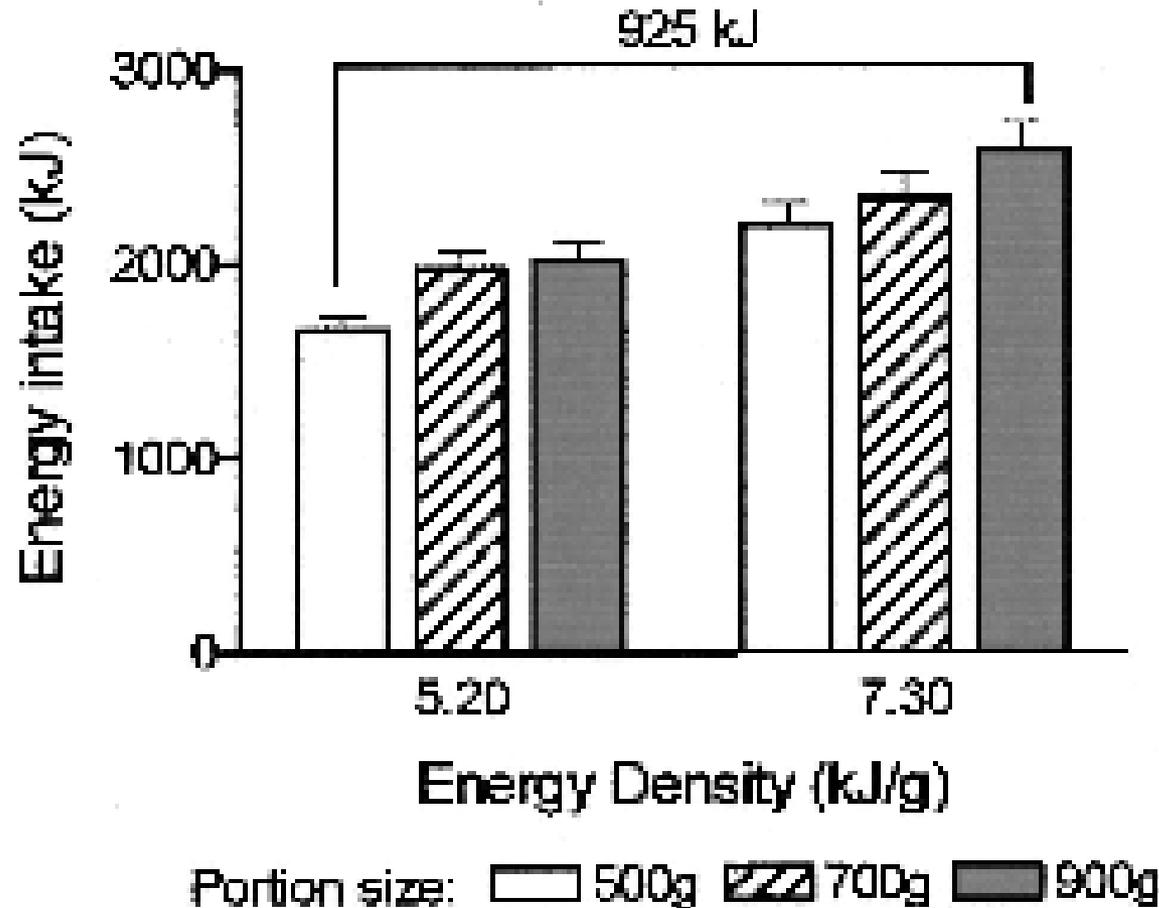
- Energy availability (portion sizes) and the way food is presented visually can influence energy intake of a meal.
- Atmosphere cues like social influences, temperature, and lighting can influence energy intake of a meal.
- Increasing variety can increase energy intake and weight gain

Factors that influence energy intake: Food Energy Density

- Key factors influencing energy density are water and fat content
- Covert manipulation of energy density (no chance for learning) greatly effects energy intake
 - Increasing ED increases EI
 - Decreasing ED decreases EI
- Consumption of higher energy density foods are associated with higher energy intake and body weight

Factors that influence energy intake: Food Energy Density

There is an interaction between portion size and energy density.
(Kral et al. Am J Clin Nutr 2004;79:962–8.)



Factors that influence energy intake: Food Macronutrients

- Animals do reasonably well at self-selection of a “balanced diet”
- Macronutrient self-selection is relatively consistent within species, and highly consistent day-to-day for a given animal

Factors that influence energy intake: Food Macronutrients

- “High fat” (low carb, similar protein) diets increase energy intake

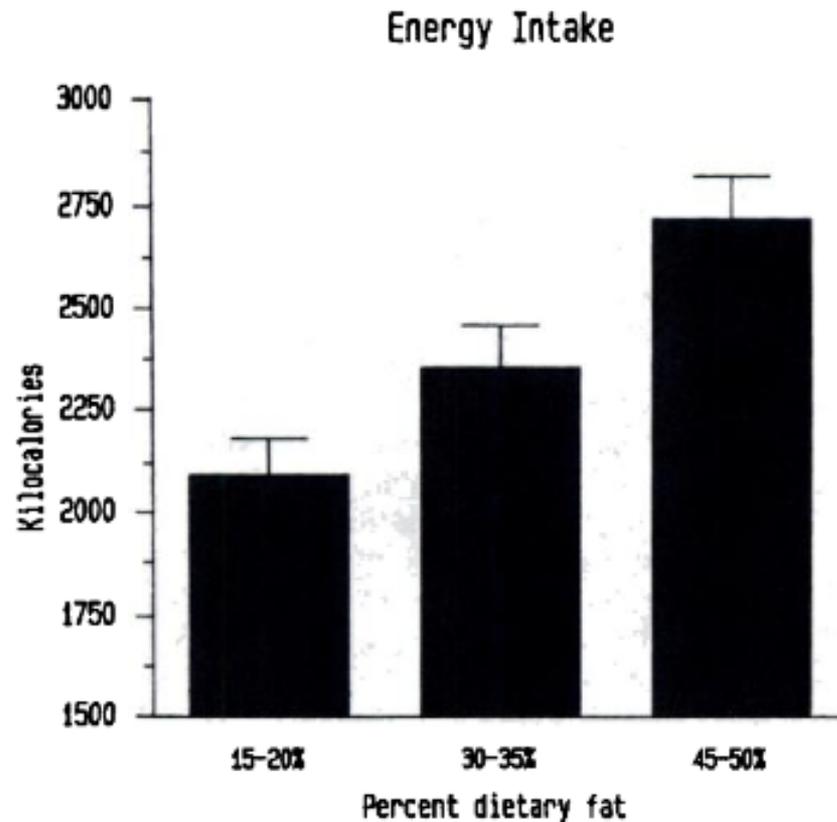


FIG 1. Mean daily energy intake per 14-d dietary treatment + SEM
F test for diet effect: $p < 0.0001$.

Factors that influence energy intake: Food Macronutrients

- The effect of fat on energy intake is diminished when energy density is controlled for.

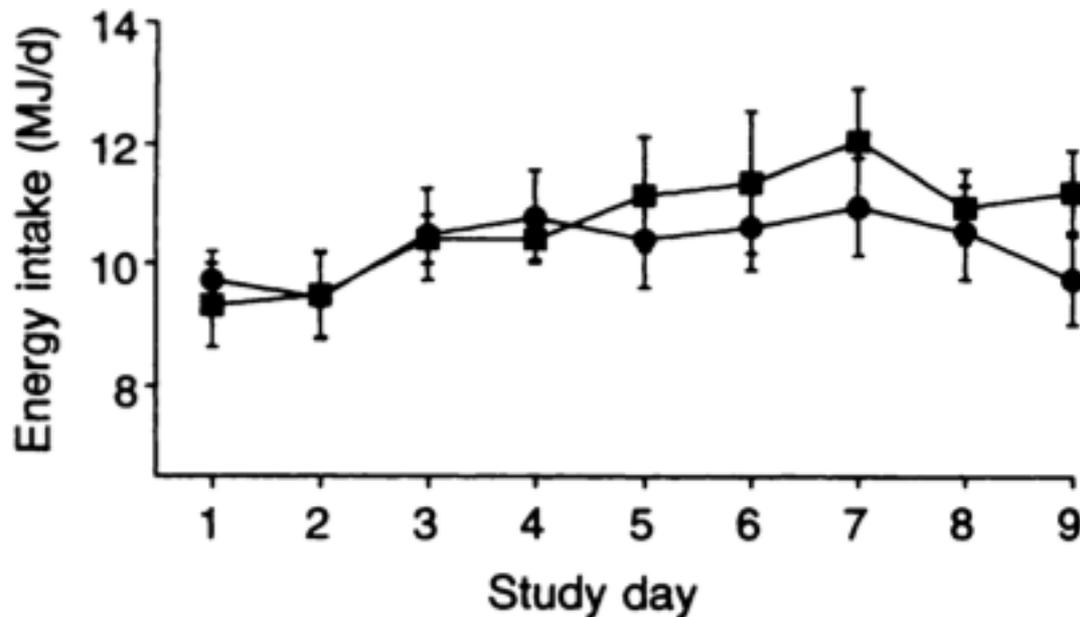


FIGURE 1. Mean (\pm SEM) voluntary energy intake over 9 d of consumption of low-fat (●) and high-fat (■) diets.

Factors that influence energy intake: Food Macronutrients

- Protein is consistently more satiating than carbohydrate and fat in the short-term (Poppitt et al. *Physiol Behav* **64**(3): 279-285.)
- Rats compensate well for dilutions in protein, but not for dilutions in carbohydrate (Roizin J *Comp Physiol Psychol* **65**(1): 23-29.)

Factors that influence energy intake: Food Macronutrients

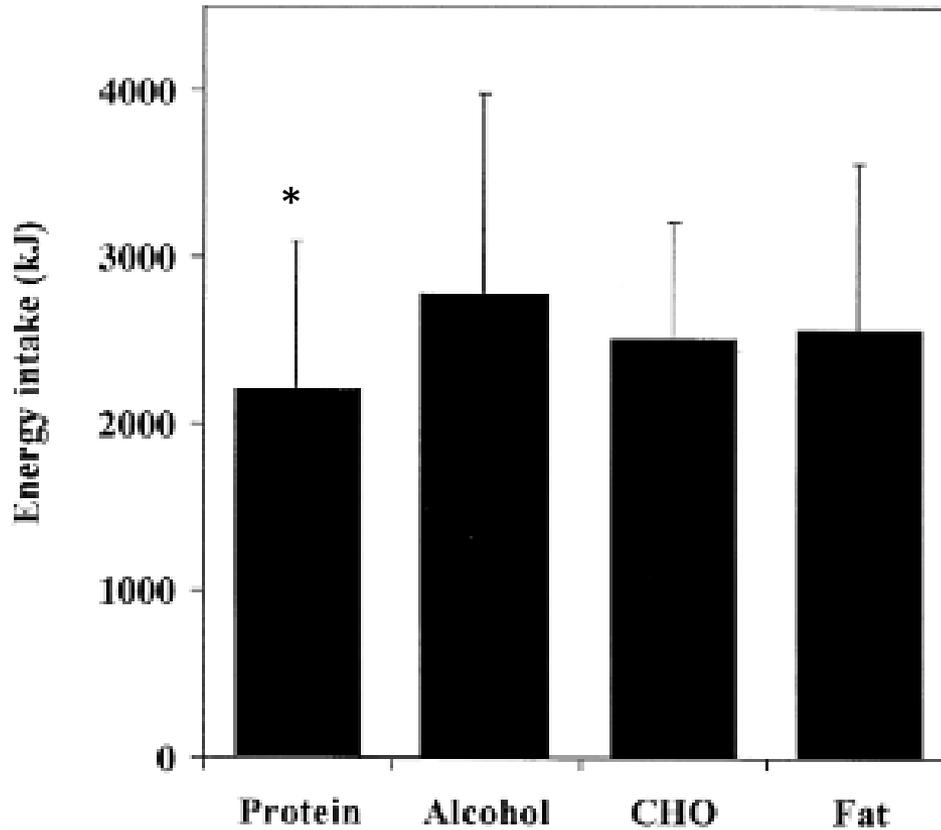


FIG. 3. Energy intake at an ad lib. lunch 120 min after ingestion of 1-MJ preload supplements of protein, carbohydrate (CHO) and fat (mean \pm sd) alcohol.

(Poppitt et al. *Physiol Behav* **64**(3): 279-285.)

Factors that influence energy intake: Food Macronutrients

Ad libitum high protein diets reduce calorie intake and the effect is persistent for 90 days.

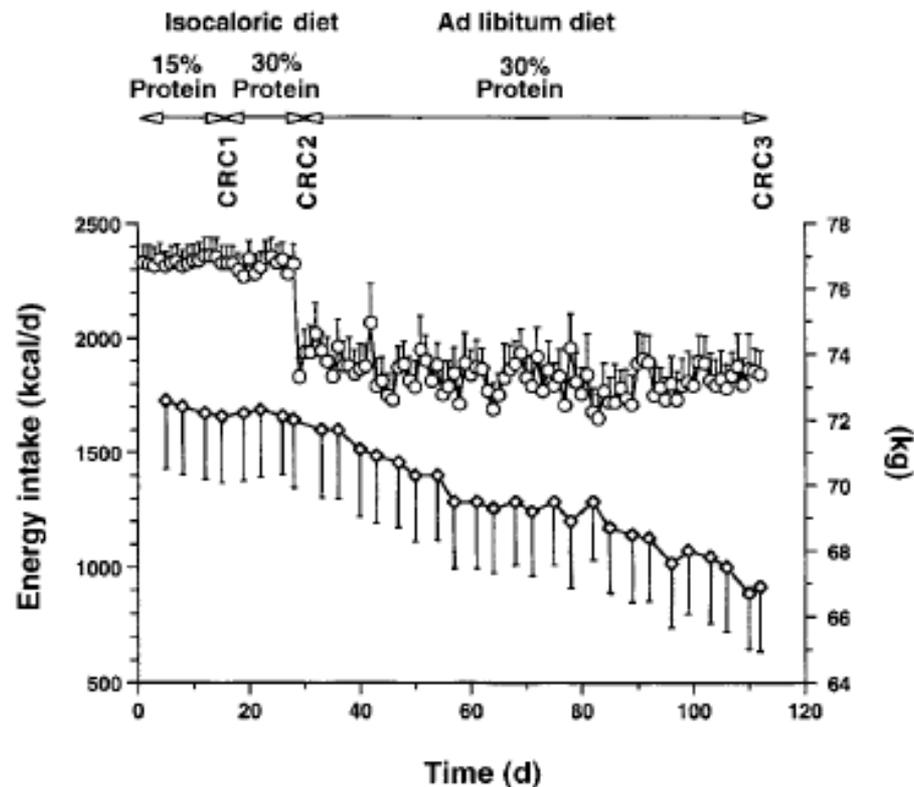


FIGURE 1. Mean total daily energy intake (○) and body weight (◇) for 19 healthy subjects plotted against day of study. The sequence of study diets and timing of visits 1, 2, and 3 to the General Clinical Research Center (CRC1, -2, and -3) are indicated. The bars represent SEs.

Factors that influence energy intake: Food Macronutrients

High levels of protein suppress food intake, but lower levels may not increase it. (Martens et al. Am J Clin Nutr **97**(1): 86-93.)

Mean energy and macronutrient intake and change in body weight over 12 d between conditions: whey-protein and soy-protein groups combined ($n = 79$)¹

	Percentage of energy from protein		
	5%	15%	30%
Energy intake (MJ/d)			
Total	9.33 ± 3.52 ^{2,a}	9.62 ± 3.51 ^a	7.21 ± 3.08 ^b
Snacks	2.15 ± 2.09 ^a	2.44 ± 2.35 ^a	1.16 ± 1.13 ^a
Meals	7.18 ± 2.38 ^a	7.13 ± 2.39 ^a	6.04 ± 2.12 ^b
Breakfast	2.56 ± 0.91 ^a	2.38 ± 0.91 ^b	2.19 ± 0.93 ^c
Lunch	2.10 ± 0.90 ^a	2.02 ± 0.88 ^a	1.56 ± 0.68 ^b
Dinner	2.52 ± 0.99 ^a	2.73 ± 1.03 ^b	2.29 ± 0.94 ^c
Protein intake, meals			
(MJ/d)	0.36 ± 0.12 ^a	1.07 ± 0.36 ^b	1.81 ± 0.64 ^c
(g · kg BW ⁻¹ · d ⁻¹)	0.3 ± 0.1 ^a	0.9 ± 0.3 ^b	1.6 ± 0.5 ^c
Carbohydrate intake, meals			
(MJ/d)	4.31 ± 1.43 ^a	3.57 ± 1.20 ^b	2.12 ± 0.74 ^c
(g · kg BW ⁻¹ · d ⁻¹)	3.7 ± 1.2 ^a	3.1 ± 1.1 ^b	1.8 ± 0.6 ^c
Fat intake, meals			
(MJ/d)	2.51 ± 0.83 ^a	2.50 ± 0.84 ^a	2.12 ± 0.74 ^b
(g · kg BW ⁻¹ · d ⁻¹)	1.0 ± 0.3 ^a	1.0 ± 0.3 ^a	0.8 ± 0.3 ^b
Protein:carbohydrate + fat			
Meals (% of energy)	5:95 ³	15:85	30:70
Total (% of energy)	5:95	12:88	23:77
ΔBW _{day12 - day1} (kg)	-0.9 ± 1.1	-0.8 ± 1.0	-1.0 ± 1.0
Energy balance (MJ/d)	-2.48 ± 2.92 ^a	-2.20 ± 2.84 ^a	-4.61 ± 4.64 ^b

¹ Values with different superscript letters are significantly different, $P < 0.05$ (repeated-measures ANOVA with Bonferroni correction for pairwise post hoc comparisons). BW, body weight.

Factors that influence energy intake: Food Form: Liquid vs. Solid

- Some evidence suggests liquids may not be compensated for as well as solids (keep in mind these are self-report data)

June 2000, Volume 24, Number 6, Pages 794-800
Liquid versus solid carbohydrate: effects on food intake and body weight

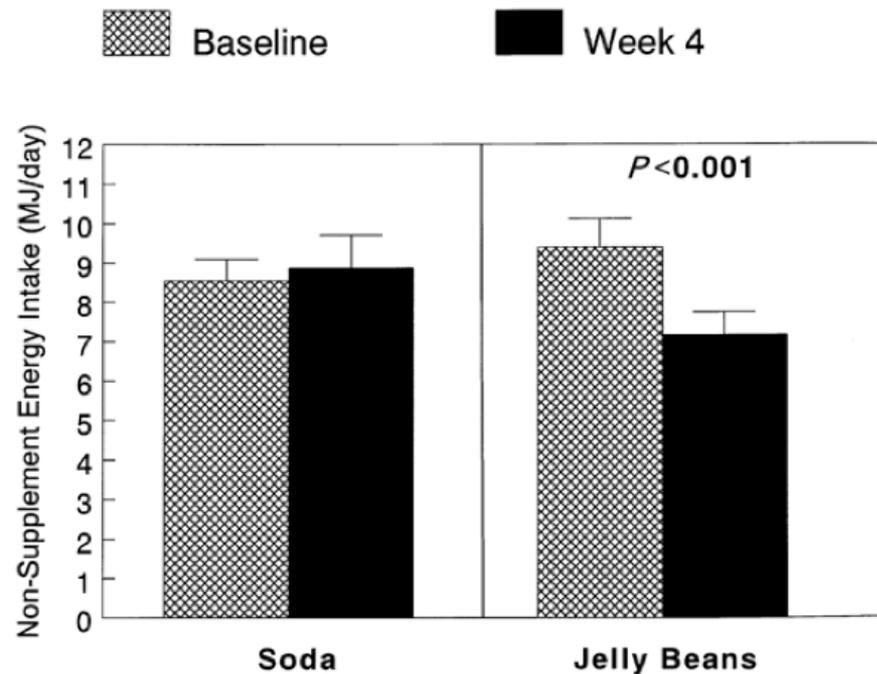


Figure 1 Mean reported energy intake (s.e) prior to and at the end of both intervention periods.

Factors that influence energy intake: Food Form: Liquid vs. Solid

Regardless of food being high in protein, carbohydrate, or fat, liquid calories lead to imperfect compensation over 1 day compared to solid calories.

	Beverage	Solid	p
High Protein	-54 ± 102	127 ± 58	0.02
High Carbohydrate	-8 ± 77	152 ± 52	0.006
High Fat	-179 ± 97	42 ± 48	0.016

Units are % total daily compensation. 0 indicates perfect compensation, negative indicates eating more food than baseline, and positive indicates eating less food than baseline. (Mourao et al. International Journal of Obesity (2007) 31, 1688–1695)

Factors that influence energy intake: Food Food Form: Liquid vs. Solid

- Meta-analysis of RCTs that added nutritively sweetened beverages to diet suggest they may lead to some weight gain (Mattes et al. 2011 [Obes Rev.](#) 2011 May;12(5):346-65)

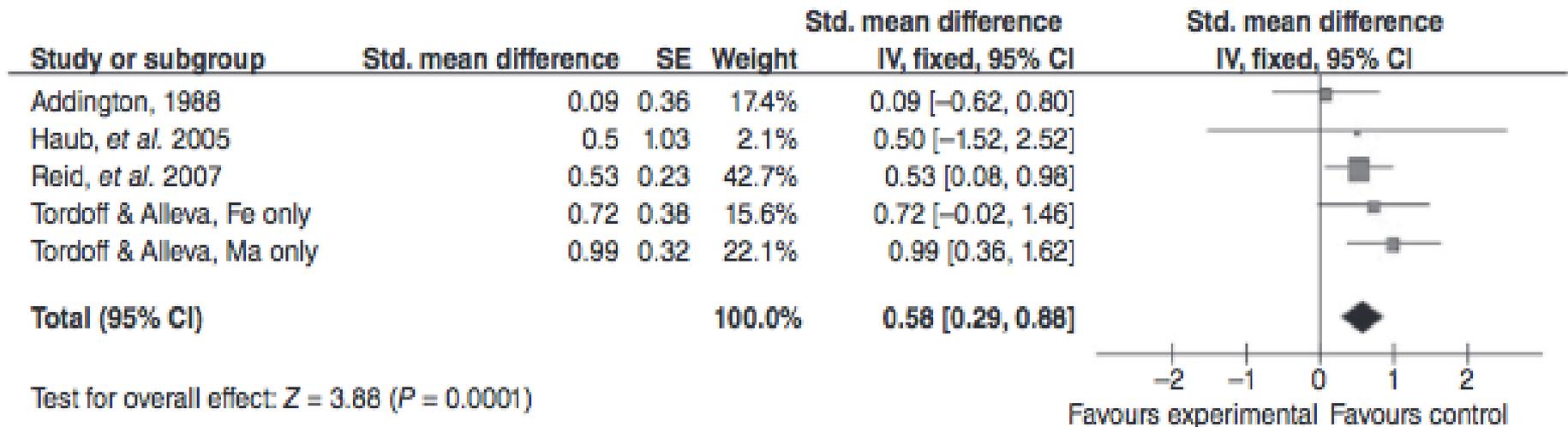


Figure 3 Forest plot comparing studies of added nutritively sweetened beverage (NSB) consumption. See meta-regression section for heterogeneity statistics. Figure above does not represent dose-response relationship of added NSBs and weight. See Fig. 2 for dose-response graph.

Factors that influence energy intake: Food

Summary

- We can make conclusions about diets of a *particular macronutrient composition*:
 - Diets with high levels of protein tend to suppress energy intake
 - Diets high in fat/energy density tend to increase energy intake
- High calorie liquid added to the diet may not be well compensated for, increase energy intake, and lead to a small amount of weight gain

Conclusions

- What is something new that you learned today?
- What overarching conclusions & principles did you draw from this lecture?