The Effect of Dietary Energy Density on Satiety and Satiation

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The energy density (ED) of food components

- Fat: 9 kcal/g
- Alcohol: 7 kcal/g
- Carbohydrate: 4 kcal/g
- Protein: 4 kcal/g
- Fiber: 1.5 – 2.5 kcal/g
- Water: 0 kcal/g
Adding water reduces energy density, even of high-fat foods.

Fat: 9 kcal/g
Water: 0 kcal/g
Fat + Water: 4.5 kcal/g

Adding water decreases the energy density of foods, even high-fat foods.
# Water content of foods

<table>
<thead>
<tr>
<th>Food</th>
<th>Water Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soup</td>
<td>85-95</td>
</tr>
<tr>
<td>Fruits and Vegetables</td>
<td>80-95</td>
</tr>
<tr>
<td>Hot Cereal</td>
<td>85</td>
</tr>
<tr>
<td>Egg, boiled</td>
<td>75</td>
</tr>
<tr>
<td>Pasta</td>
<td>65</td>
</tr>
<tr>
<td>Fish and seafood</td>
<td>60-85</td>
</tr>
<tr>
<td>Meats</td>
<td>45-65</td>
</tr>
<tr>
<td>Bread</td>
<td>35-40</td>
</tr>
<tr>
<td>Cheese</td>
<td>35</td>
</tr>
<tr>
<td>Nuts</td>
<td>2-5</td>
</tr>
<tr>
<td>Oil</td>
<td>0</td>
</tr>
</tbody>
</table>
For weight management should macronutrient content be the only focus?

Two options with the same calories and % macronutrients
Satiety: Can consumption of a low-ED preload affect intake at the meal?
Effects on energy intake of water as a beverage or in food

Rolls et al., Am J Clinical Nutrition, 70, 448-455, 1999
Water in a food, but not as a beverage, reduced energy intake at lunch

Rolls et al., Am J Clinical Nutrition, 70: 448-455, 1999
How does energy density affect food intake and satiety?
Visual and cognitive cues related to the amount of food are important

- Adding air to a food decreased intake and enhanced satiety
- Foods with irregular shapes that look bigger were associated with lower intake
Amount of sensory stimulation is important

- Sensory-specific satiety is affected more by the volume consumed, than by the energy consumed.
Physiologic cues related to preload volume affect satiety

- Participants responded to differences in the volume of intragastric preloads
- Need more studies on how energy density affects stomach emptying and satiety hormones
Summary:
Energy density can affect satiety

- Likely that the effect is due in part to cognitive influences
- Volume of food consumed affects sensory-specific satiety
- Volume of food infused intragastrically affects satiety
- Need more studies to determine critical variables
  - Portion size/volume
  - Energy content and ED
  - Form (solid/liquid, viscosity)
  - Macronutrients
Satiation:
How do variations in energy density affect *ad libitum* consumption?
Reducing energy density and fat content decreased *ad lib* intake over 5 days.

**Food Intake (g)**

- Low-fat (Low-ED)
- High-fat (High-ED)

**Energy Intake (kcal)**

- Low-fat (Low-ED)
- High-fat (High-ED)

*Duncan, Bacon & Weinsier, Am J Clinical Nutrition, 37: 763-767, 1983*
<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Length</th>
<th>Effect on energy intake</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fat content decreased and energy density held constant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van Stratum et al., 1978</td>
<td>22</td>
<td>2 phase, 14 d each</td>
<td>None</td>
</tr>
<tr>
<td>Stubbs et al., 1996</td>
<td>6</td>
<td>3 phase, 14 d each</td>
<td>None</td>
</tr>
<tr>
<td>Saltzman et al., 1997</td>
<td>14</td>
<td>2 phase, 9 d each</td>
<td>None</td>
</tr>
<tr>
<td>Rolls et al., 1999</td>
<td>34</td>
<td>4 weeks, 4 d each</td>
<td>None</td>
</tr>
<tr>
<td>Raben et al., 2003</td>
<td>19</td>
<td>4 weeks, 1 d each</td>
<td>None</td>
</tr>
<tr>
<td><strong>Energy density decreased and fat content held constant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stubbs et al., 1998</td>
<td>6</td>
<td>3 phase, 14 d each</td>
<td>↓</td>
</tr>
<tr>
<td>Bell et al., 1998</td>
<td>18</td>
<td>3 weeks, 2 d each</td>
<td>↓</td>
</tr>
<tr>
<td>Rolls et al., 1999</td>
<td>34</td>
<td>4 weeks, 4 d each</td>
<td>↓</td>
</tr>
<tr>
<td>Bell et al., 2001</td>
<td>36</td>
<td>6 weeks, 1 d each</td>
<td>↓</td>
</tr>
<tr>
<td>Kral et al., 2002</td>
<td>40</td>
<td>3 weeks, 1 d each</td>
<td>↓</td>
</tr>
</tbody>
</table>
What is the effect of reducing the ED of mixed dishes on *ad lib* intake?

- ED was reduced by increasing proportion of vegetables.
- Macronutrient composition (%) was kept constant.

*Bell et al., Am J Clinical Nutrition, 67: 412-420, 1998*
Reducing ED by 30% reduced energy intake by 30%


Means with different letters are significantly different (p < 0.05).
If either fat content or energy density of a portion of the diet is manipulated and other foods can be consumed ad libitum, what is the effect on energy intake?

- 50% of diet manipulated for 4 successive days in each condition:
  
  (1) varied fat content and held energy density constant
  
  (2) varied energy density and held macronutrient content constant

Effect of fat content (16.4 vs. 36.5%) of compulsory foods on mean daily intake

Effect of energy density of compulsory foods on mean daily intake

* Significantly different at p<0.025

Does energy density have similar effects in preschool children?

- Does reducing the ED of breakfast, lunch, and afternoon snack served over 2 days at daycare influence 3- to 5-year-old children’s daily energy intake?

- Will children compensate for reductions in energy intake by increasing their intake of:
  - dinner and evening snack at home (ED not manipulated)
  - foods on a second day

Example of the test meals

- Added fruits and vegetables to recipes
- Reduced fat and sugar

<table>
<thead>
<tr>
<th></th>
<th>Higher-ED</th>
<th>Lower-ED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MEAL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Breakfast</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>0.60</td>
<td>0.42</td>
</tr>
<tr>
<td>Coffee cake</td>
<td>3.60</td>
<td>2.83</td>
</tr>
<tr>
<td>Peaches</td>
<td>0.55</td>
<td>0.40</td>
</tr>
<tr>
<td><strong>Lunch</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>0.60</td>
<td>0.42</td>
</tr>
<tr>
<td>Baked pasta</td>
<td>1.60</td>
<td>1.20</td>
</tr>
<tr>
<td>Green beans</td>
<td>0.72</td>
<td>0.51</td>
</tr>
<tr>
<td>Applesauce</td>
<td>0.71</td>
<td>0.52</td>
</tr>
<tr>
<td><strong>Snack</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cranberry grape juice</td>
<td>0.61</td>
<td>0.45</td>
</tr>
<tr>
<td>Chocolate chip cookie bar</td>
<td>4.67</td>
<td>3.74</td>
</tr>
</tbody>
</table>
ED did **not** affect the weight of food consumed over 2 days.
ED did influence energy intake over 2 days

14% (389 kcal)

Day 1 Day 2

Higher-ED Lower-ED

Cumulative energy intake (kcal)
Effects of reductions in energy density on satiation

- If palatability was controlled, both adults and children ate a similar weight of food
- Therefore decreasing the ED of food was associated with a reduction in energy intake
- In adults, there was no increase in hunger or in food intake at the next meal
How do two strategies to reduce the ED of the diet affect weight management?

RF Group:
- Reduce fat intake and restrict portions

RF + FV Group:
- Increase intake of high-water/high-fiber foods
  - Vegetables, fruits, soups
- Emphasize portion control only for energy-dense foods
  - High-fat foods and foods with low moisture content

Neither group counted calories or fat grams
Both groups were successful, but the RF + FV group lost more weight

Both groups were successful, but the RF + FV group lost more weight

Both groups were successful, but the RF + FV group lost more weight

The RF+FV group ate more food and more fruit and vegetables, and reported less hunger.

*Significant differences between groups (p < 0.0001)*
Is weight loss related to change in ED in large-scale trials such as PREMIER?

- Large, multi-center clinical trial testing the influence of three dietary interventions
  1. Advice group: one counseling session
  2. Established group: 18 contacts (decrease fat and portions)
  3. Established + DASH group: 18 contacts

- The DASH diet recommendations:
  - 9-12 servings/day fruits and vegetables
  - 2-3 servings/day low-fat dairy products
  - < 25% of energy from fat

Weight loss at 6 months was correlated with the decrease in food ED

Since ED changes were achieved by each treatment group, analyses were conducted with the three groups combined

\[ r = 0.28 \]  
\[ p < 0.001 \]

PREMIER participants were categorized by change in ED after 6 months

- Small decrease in ED or increase in ED (n = 219)
- Modest decrease in ED (n = 220)
- Large decrease in ED (n = 219)

**Change in Food Weight**

- Food weight (g/d)
- +297
- +73
- +91

**Change in Energy Intake**

- Energy intake (kcal/d)
- +11
- -278
- -511

**Change in Body Weight**

- Body weight (lb)
- +73
- -511
- -13
Higher-ED diets were associated with greater weight gain in women

Longitudinal and population-based studies

- Increases in ED were associated with greater weight gain in 50,000 women over 8 years
  

- Self-reported intakes by free-living children and adults have shown that normal-weight individuals consume diets lower in ED than obese individuals
  - Lower ED diets are more expensive
For 325 calories:

Strategies to incorporate ED and satiety into weight management

- Increase variety and availability of low-energy-dense foods

- Increase intake of high-water foods
  - Vegetables, fruits, soups
  - Whole grains and legumes

- Emphasize portion control for energy-dense foods
  - High-fat foods
  - Foods with low moisture content

- Need innovative strategies to modify foods to give consumers satisfying portions, good value and taste, optimal nutrition, and fewer calories
Two strategies for eating 1575 kcal during a day

Food ED = 2.3
Food ED = 0.52

The lower the ED, the bigger the portion
Category 1:
Can eat satisfying amounts without consuming too many calories

Rolls, The Volumetrics Eating Plan, HarperCollins, 2005
Category 2:
Many foods come from this category;
Can consume relatively large portions
Category 3:
Be careful of portion size, especially at the high end of this broad range of foods
Category 4:
Need to manage consumption from this category; Limit portions or make substitutions.
Enhancing public understanding of the influence of energy density on intake

The future will bring many foods that claim to enhance satiety. Will these be effective for both optimal nutrition and weight management in an “obesogenic” environment?