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Exploring Weight Regulation using *Stella* Modeling Software

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Introduction

Weight loss is a high-interest subject among most students. This exercise is used in introductory biology laboratories at Clemson University. It asks students to determine their Body Mass Index, and then estimate the percent body fat of a student volunteer by both skinfold thickness and impedance analysis. Finally, the students explore weight regulation using both a simple *Stella* model that the students construct themselves, plus a more complex model derived from the literature.

Because of space limitations, this manuscript only includes the notes to the instructor portion of the exercise. The student exercise and four *Stella* models (for both Macintosh and Windows) are posted on a Clemson Web site (http://biology.clemson.edu/bpc/bp/Lab/111/weight.html). Download instructions appear at the end of the article.

Materials

The exercise requires skinfold thickness calipers, impedance analyzers, computers, and several *Stella* models. Our skinfold thickness calipers are “Figure Finders” or “Fat-O-Meters” from Novel Products, ordered from Ward’s (catalog number 14W5058). They cost $14.50 US each. Our impedance analyzer was a “Body Logic Body Fat Analyzer” from Omron Health Care, also ordered from Wards (catalog number 14W5064) and cost $69 US each. The lab should be equipped with one skinfold thickness caliper per four students, and one impedance analyzer for every eight students. For software usage, there should also be one Windows or Macintosh computer per four students.

Figure 1. The skinfold thickness calipers (left) and the impedance analyzer (right). The right picture also shows the correct grip to use with the impedance analyzer.

The <http://biology.clemson.edu/bpc/bp/Lab/111/weight.html> Web site has 4 *Stella* programs: "Linear Fat" (constructed by students for Exercise B1), "Exponential Fat" (constructed by students for Exercise B2), and "Ref Man" and "Ref Woman," the much more complex models used without modification by the students for Exercise C. These programs require *Stella* Version 6.0 or later.

In spring of 2004, *Stella* 8.1 could be obtained from: ISEE Systems, Inc
46 Centerra Parkway, Suite 200
Lebanon, NH 03766
Phone 603-643-9636
http://www.iseesystems.com/

ISEE sells multiple copies of Stella in units called Lab Packs. In spring of 2004, prices for a Lab Pack of at least 5 units was $150 US per unit (that is, a minimum of $750). A faculty license for a single copy was $649 US. A student license (only good for six months) was $129 US.

Implementation Notes

At Clemson, a smaller version of this exercise was inserted into a lab on the immune system, and was completed in less than one hour. At the time the students performed this exercise, they have had a previous introduction in lecture to the obesity public health problem, kcal as a measure of diet and metabolism, and BMIs; they had had no introduction to the models or impedance analysis.

The BMI, Skinfold, and Impedance Analysis Exercises

Because of privacy concerns, the BMI and percent body fat measurements of students who are not volunteers should not be revealed in the laboratory. However, we had no problem securing one volunteer per group of four who was willing to have the measurements done on himself/herself.

The students should be warned that the skinfold thickness measurements should be done exactly as described in the student directions. The key to a successful impedance analysis is to press the palms firmly into the metal plates in the handles so good electrical contact with the skin can be made (Fig. 1).

The Modeling Exercises

The student exercise uses two Stella models. Exercise B uses a "bare-bones" model of weight regulation constructed by the students using the step-by-step instructions in the exercise. The main lessons taught by this exercise are that even under the simplest set of assumptions, a certain diet will produce an equilibrium weight rather than a weight that increases or decreases indefinitely. Even if the fat stores are artificially increased or decreased, the equilibrium fat stores will return if the diet remains unchanged.

Exercise C uses a pair of more elaborate models ("Ref Man" and "Ref Woman"). While the student models used arbitrary units, "Ref Man" and "Ref Woman" use literature-based data on average body composition, metabolic rates, and the costs of activities as cited in McArdle *et al.* (2001), a leading text on exercise physiology. Both Mac- and Windows-based versions of these programs are available at <http://biology.clemson.edu/bpc/bp/Lab/111/weight.html>.

"Ref Man" and "Ref Woman" divide the human body into four compartments:

a) Fat-free mass (FFM) exclusive of glycogen (57.6 kg for the man and 40.2 kg for the woman);

b) Glycogen reserves (2000 kcal or for the man and 1350 kcal for the woman). When hydrating water is added, the glycogen reserves have a mass of 2.1 kg and 1.4 kg for the man and woman;
c) Storage fat, the fat that rises and falls as we diet and gain weight (63,987 kcal or 8.3 kg for the man and 65,450 kcal or 8.5 kg for the woman);
d) Essential fat, or fat associated with internal organs like the liver and heart, and which is necessary for normal physiological function (2.1 kg for the man and 6.8 kg for the woman). Essential fat is not gained and lost in "Ref Man" and "Ref Woman."

The foci of the model are storage fat and glycogen. Both of these are increased by ingestion of kcal and decreased by metabolism. When there is an imbalance between the diet and metabolism, the glycogen reserves are the first to go up in the case of a dietary excess and to decline in the case of a dietary deficit, but they may not rise beyond a certain percentage of the lean body mass. This produces a rapid weight loss when a diet is started, but 70% of this loss is water and most of the rest is glycogen, not fat. If glycogen reserves are low, fat is slowly converted into glycogen. If storage fat goes to zero, the model no longer gives reliable results because it cannot break down essential fat or lean body mass. Therefore, if storage fat becomes zero, the model calculations stop automatically.

Metabolism is broken down into several components:

a) Resting metabolic rate (RMR) is proportional to lean body mass, and may be changed by the user (Exercise C4).
b) If an option called the fat set point is active (Exercise C5), the RMR declines when storage fat is lower than the set point and increases when storage fat is above the set point. An active fat set point can lower RMR to 50% of normal when fat is too low and raise it to 150% of normal when fat is too high.
c) Both the reference man and reference woman have sedentary lifestyles that involve sitting (50% of the time), lying down (15%), typing (15%), standing (10%), writing (8%), and walking at 2.5 mph (2%) during the 16 hours the person is awake. Only resting metabolism goes on during the 8 hours of sleep.
d) The simulated person may exercise by jogging at 5.2 mph or walking at 3 mph (both on a level surface). The net energetic expenditures from this exercise (costs above RMR) are proportional to body mass.
e) Peristalsis and digestion of food have a caloric cost called "diet-induced thermogenesis." This uses up 20% of food calories.

The models make no attempt to model appetite. If a variable called "Diet Compliance" is set at 100%, the simulated person ingests exactly the diet number of kcal each day (and exercises as instructed by the user). If "Diet Compliance" is set to a number below 100%, the person goes off his/her weight loss regime on random days. For example, if Diet Compliance is set at 75%, on 75% of all days, the simulated person eats the diet number of kcal and exercises. On 25% of days, the person eats the number of kcal needed to maintain the person's *original* weight (e.g., the amount of kcal the person presumably "wants" to eat) and doesn't exercise. If Diet Compliance is set at 0%, the person ignores dieting and exercise, and his/her weight will remain at its original value.

The main lessons of each of the exercises in Part C are as follows:

C1. A certain diet produces a certain equilibrium body fat. This occurs because as the body gets heavier, it requires more energy to move it, and so eventually energy expenditure rises to match to kcal input in the diet.

C2. Weight loss with either diet alone or exercise alone is difficult; a combination of diet and exercise is best. Also, substantial fat loss takes an amazingly long time—sometimes hundreds of days for moderate diet and exercise.

C3. Lapses from a diet are not as damaging as generally believed. Lapses should be minimized, but the important thing is not to go off the diet permanently because of discouragement about lapses. Substantial weight loss can be still achieved as long as the *average* amount eaten is less than before the diet began.

C4. Small variations in resting metabolic rate (RMR) can have powerful effects on weight loss or gain. This is one reason that exercise is so important—in addition to its direct consumption of calories, exercise elevates RMR even after the exercise is over.

C5. If there is an active fat set point (a quantity of fat that the body tries to maintain by lowering the metabolic rate when fat stores are low), the weight can be very resistant to change even when the person diets and exercises virtuously. This applies to both people trying to lose weight and people trying to gain weight.

One weakness of "Ref Man" and "Ref Woman" is that they don't consider appetite or hunger, the other half of the weight regulation picture. They also don't distinguish between dietary macromolecules (e.g., low-carbohydrate diets) since at this writing it seems that the long-term effect of a diet on fat stores depends on the kcal eaten, not the macromolecules eaten. Finally, the models are only accurate while storage fat is present. They cannot simulate the breakdown of essential fat or lean body mass. To avoid giving inaccurate results, the model stops automatically when storage fat becomes zero.

The "Weight Loss Revolution" Transparency

When covering weight regulation in class, I use a tongue-in-cheek transparency called, "Dr. Kosinski's Weight Loss Revolution (Not!)" that summarizes the major points about weight loss that I have gleaned from the literature. A transparency master is presented on the next page.

Downloading the Student Exercise and the Models from the Web

The download Web site is <http://biology.clemson.edu/bpc/bp/Lab/111/weight.html>. It contains two compressed files: Mac Weight and Windows Weight. When expanded, each of these files will generate these Instructor's notes, the student exercise (a 16-page Word document) and four *Stella* models: "Linear Fat," "Exponential Fat," "Ref Man," and "Ref Woman." Again, these *Stella* files require the *Stella* application to work. Follow the directions on the Web site to access the files.

Literature Cited

McArdle, W. D., F. I. Katch and V. L. Katch. 2001. Exercise physiology: energy, nutrition, and human performance. Fifth edition. Lippincott, Williams, and Wilkins, Philadelphia, 1158 pages.

The Weight Loss Revolution (Not!)

1. Eat less; exercise more.
2. Eat a balanced, healthful diet containing a variety of foods. Just be careful about kcal eaten.
3. Cut your diet to 500-1,000 kcal less per day than your daily energy expenditure. More severe diets may be counterproductive because they might cause loss of lean muscle mass, reducing metabolic rate.
4. Exercise. Exercise increases your metabolic rate. So-so exercise that you do regularly is better than a superb workout that you rarely do.
5. It is natural for your weight loss to stall repeatedly. To resume losing weight, you must eat less and exercise more.
6. This is a permanent lifestyle change. Aim for one pound of loss per week, and keep this up for months. A 5-15% weight reduction is a reasonable final goal.