Sensory Evaluation By Magnitude Estimation

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□ WHEN FORMULATING FOODS, the food technologist often can control physical parameters that give rise to taste, aroma, and texture. However, inputs provided by management, often with respect to economic considerations such as the cost of ingredients, reduce the vast array of options open to the food technologist to a few, economically feasible ones. Substitution of less expensive ingredients for costlier ones is desirable, but maintenance of product quality must be guaranteed in order to ensure repeated purchases by the consumer. Because such requirements often weigh heavily on what is produced for sale, those who are concerned with sensory evaluation of products must develop scales that assess the strength of the sensory impression, whether it be taste, smell, texture, or acceptance, and the degree to which the standards for product quality are met.

RATIO SCALING DESIRABLE

In the laboratory, the panelist may be asked to judge various aspects of a product and to indicate whether the product is too sweet, not sufficiently tender, smells too intense or too weak, etc.

Traditionally, sensory measurements developed for product evaluation fall into the class of measurement scales known as "category," "rating," or "interval" scales. Such scales give information about differences of magnitudes, but not about ratios of magnitudes. A good physical analogy is the Centigrade scale of temperature. In the interval between 40°C and 80°C lie 40 degrees of temperature. However, 80°C is not twice as hot as 40°C. Similarly, in rating the intensity of sweetness or saltiness, the strength of an aroma, or the degree of hardness of a cookie on a 9-point (or 11-point, etc.) rating scale, one can state that two samples rated 4 and 6 are separated by two categories but *not* that the sample rated 6 is 1.5 times as intense to the panelist as the sample rated 4.

Because sensory evaluation, product development, and marketing are closely intertwined, it would be useful to devise a measurement system for sensory (or preference) magnitudes that can state that product A is 5 times sweeter than product B, or that product C is twice as acceptable as product D. For the food technologist, it would also be helpful to develop a series of mathematical equations that indicate the proportional adjustments in ingredient levels needed to make a stated proportional change desired by the panelists. This equation could be reversed to indicate the expected proportional change in perceived magnitude on a sensory dimension (e.g., toughness of meat) that would match a known, instrumentally measured change on the product (e.g., Warner-Bratzler value).

This aim of developing functional relationships between the realm of the objective instrument and the realm of the subjective panelist would allow the food technologist to transform subjective estimates into ingredient levels and permit the marketer, pilot plant manager, and management to translate subjective estimates into dollar values of ingredients.

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PRODUCING A RATIO SCALE

Experimental psychologists have been using a procedure known as *magnitude estimation* to produce a scale that has ratio properties. Its use is straightforward, almost deceptively so. Panelists are presented with a series of samples, be they simple taste solutions or odorants, or complex foods and aromas, and are instructed to assign to these samples numbers to reflect perceived magnitudes. Usually the panelists are instructed to attend to one or two specific attributes of the stimulus (e.g., sweetness and pleasantness of a beverage or hardness and chewiness of a meat sample). Presumably, the experimenter has varied some physical aspect of the sample which can be measured by an objective instrument.

The panelist is instructed to assign to the first sample a number which may be either chosen beforehand by the experimenter or left to the discretion of the panelist, and then to assign numbers to the remaining samples so that the ratios among the numbers reflect the ratios of magnitudes perceived. That is, if the first sample were to be rated 10 on crunchiness and the panelist perceived the second sample as being 2½ times as crunchy as the first sample, he would give the second sample a rating of 25. No high or low limits are specified; indeed, one aim of the method of magnitude estimation is to have the panelist measure in the same way as nature measures—with ratio scale values that have no arbitrarily limited endpoints.

POWER FUNCTIONS

Figure 1 shows the results of a study in which the panelists assigned numbers to correspond to the perceived sweetness of each of five cherry drinks containing different amounts of sucrose. The left panel shows the unaveraged data on logarithmic coordinates (abscissa and ordinate); the scatter of points shows that there was variability among the panelists, a find-

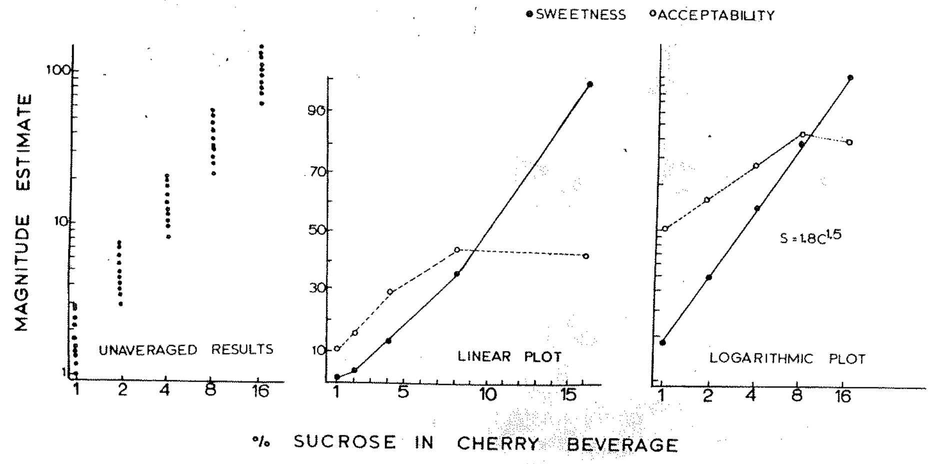

Fig. 1—**RELATIONSHIP** *between perceived sweetness, rated by magnitude estimation, and sucrose concentration. The left panel shows the unaveraged judgments plotted on logarithmic coordinates; the middle panel shows the geometric mean estimates of sweetness and acceptability plotted on linear coordinates; and the right panel shows these geometric mean estimates plotted on logarithmic coordinates—a power function graph*

ing that characterizes all such subjective assessments. The middle panel shows the relationship between the geometric mean judgment and the concentration of sucrose on linear coordinates.

Quite often a logarithmic transformation of both the stimulus and response coordinates will straighten out this curvilinearity, and render linear the relationship between physical sucrose level and perceived sweetness level, as shown in the right panel on logarithmic coordinates. This adjustment implies that the sensory-concentration curve may be described by the linear function

$$\log S = n \log C + \log k$$

or the power function

$$S = kC^n$$

where S is the sensory response and C is concentration.

Such power functions have been found useful for sensory evaluation and sensory quantification for many other attributes besides sweetness. These include odor intensity, perceived magnitudes of various texture attributes (e.g., hardness, roughness, viscosity), apparent saturation of colors, loudness of tones and noises, and brightness of lights (see Stevens, 1960 for an extensive list of these power functions).

As a unifying principle, the power function provides several important tools for the assessment of foods through sensory evaluation. First, it is a *function*, or mathematical equation, that tells the product specialist a number S that reflects the sensory judgments (e.g., sweetness) that are to be expected from adding a given amount C of ingredient (e.g., sucrose) to a product (e.g., cake, pudding). For example, if the level of sucrose in a beverage is doubled, is the perceived sweetness doubled commensurately? More than doubled? Less than doubled?

The exponent has a great deal to do with the way that individuals transform ratios of ingredients to ratios of sensory magnitudes. If the exponent n exceeds 1.0, then the sensory ratios are greater than the physical ratios. Sucrose sweetness falls into this class—doubling the sucrose concentration more than doubles the sweetness. For viscosity, a much lower exponent has been found (about 0.5), so that a 10-fold change in measured physical viscosity may be expected to

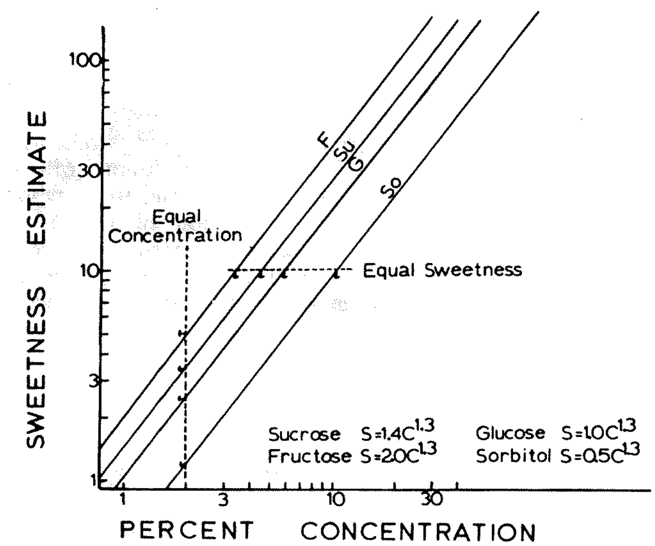

Fig. 2—**SUBSTITUTION** *of one sugar for another can be accomplished by means of a power function graph. In order to find equally sweet concentrations, one need only draw a horizontal line across the four power function lines at the desired sweetness level. Where this line intersects each sweetness function is the desired concentration of that sugar. Similarly, the sweetness of a set concentration of each sweetener is determined by drawing a vertical line*

produce only a 3.2-fold change in viscosity—a sensory ratio of $(10/1)^{0.5} = 3.2:1$.

FACILITATES SUBSTITUTIONS

Magnitude estimation and power functions may indicate trade-offs between different compounds having the same taste or the same odor. It may be relevant to exchange ingredients in a product to minimize cost or to optimize along another technological parameter (e.g., processing time). As an example, consider the trade-off between sucrose and sorbitol, fructose, or glucose. Figure 2 shows the sweetness functions for these sugars; the independent variable is concentration, and the dependent variable is magnitude estimation of sweetness. To equate sweetnesses, one need only determine the desired sucrose sweetness, find its magnitude estimate (e.g., 18), and then trace a line horizontally across the graph to determine what concentration of sorbitol, fructose, or glucose corresponds to a sweetness of 18.

Another problem might be to determine the sensory implications of halving the concentration of sucrose in a product to halve the cost of this ingredient. If the sweetness level is 10 for the starting product, then what sweetness level corresponds to the halved concentration? To answer this question, one need only find the new sucrose concentration and look up its sweetness value. Since sucrose sweetness increases as an accelerating function of concentration, halving the sucrose level produces even a greater decrement in judged sweetness.

As another example of how magnitude estimation can be used to assist in developing trade-off relationships among cost, weight, and sweetness, the sweetness of sodium saccharin and sucrose was determined experimentally; within limited ranges, the sweetness equations shown in Figure 3 apply. Sucrose sweetness, with an exponent greater than 1.0, increases more rapidly than concentration (10:1 increments in sucrose produce 20:1 increments in perceived sweetness). Saccharin sweetness, with an exponent of 0.8, increases less rapidly than concentration (10:1 increments in saccharin produce 9:1 increments in sweetness). If the sweetness function and the cost per unit weight of each sweetener are known, then the user can estimate the changes in cost to be expected as a function of changes in desired sweetness level.

For example, a 10-fold increase in sweetness, from 1 to 10, requires a 17.78-fold change in the amount of saccharin, and thus a 17.78-fold increase in cost. For sucrose, the same 10-fold change requires only a 5.88-fold increase in the amount, and thus the cost, of the sweetener. Although saccharin is initially cheaper, percentage increases in sweetness produce relatively greater increases in the cost of saccharin than in the cost of sucrose, even though using saccharin is always the cheaper option. Similar considerations can be made to determine the expected change in weight per change in sweetness level.

OPTIMIZING FORMULATIONS

The method of magnitude estimation can also be used to optimize ingredient levels in a product. Frequently in sensory evaluation, panelists act only as a meter that registers "accept" or "reject" (or "too sweet," "just right," or "not sweet enough"). A recent study (Moskowitz, 1972) suggested that the panelist might effectively be inserted into the sequence of evaluations that lead to a product, and that he might, with appropriate instructions, indicate the degree to which a food needs to be made additionally sweeter, the degree to which the flavor intensity must be reduced, etc.

The optimization procedure is relatively straightforward in theory. Panelists are presented with a series of products in which one ingredient or treatment

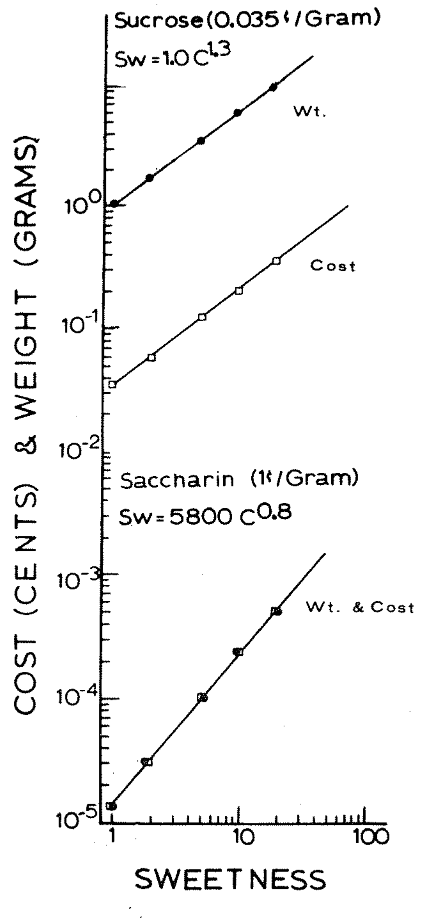

*Fig. 3—**RELATIONSHIP** between cost (open squares), weight (dots), and sweetness of sucrose (upper lines) and saccharin (lower line)*

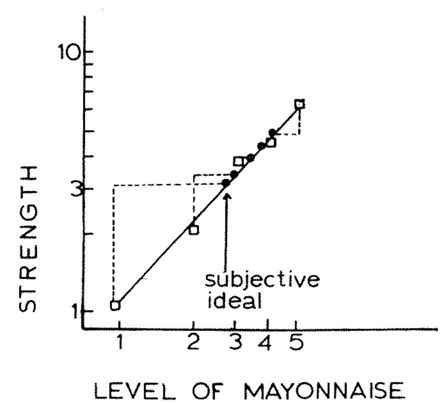

*Fig. 4—**OPTIMUM MAYONNAISE LEVEL** (dots) in a tuna fish spread is determined by multiplying the perceived level of mayonnaise (open squares) by the panelist's desired percentage change*

is viewed (e.g., the mayonnaise content in a tuna fish spread, the concentration of sucrose in a beverage, or the average size of the grind of hamburger). For each sample, the panelist is instructed to rate two things: (a) the perceived magnitude of the dimension being scaled (e.g., the apparent amount of mayonnaise in the spread, the sweetness of the beverage, or the "chunkiness" of the hamburger) and (b) the percentage change (either increasing or decreasing) that he feels should be made in order to produce an optimum level. The procedure is to multiply the percentage change desired by the panelist by the sensory magnitude given to the sample being rated. The product of this multiplication defines a new sensory level corresponding to the optimum. What is needed is an equation that relates sensory levels to physical concentrations or to physical measurements. The sensory scaling portion of the experiment provides just such an equation, and through it one can determine the physical magnitudes that produce the estimated "sensory optima."

Figure 4 shows an illustration of this approach. The squares are the perceived mayonnaise levels in a tuna fish spread, and the dots are the optimum levels obtained by multiplying the perceived levels by the percentage change desired. Note that the five ideal levels vary somewhat; among the five lies an average "ideal." The panelists gave the product with level 1 of mayonnaise a strength rating of 1 and expressed a desire for a sample containing 3 times that level of mayonnaise. Similarly, the panel wanted the level of mayonnaise in the sample containing level 5 lowered. Since the sample with level 3 received the least percentage change desired, it was the subjective optimum; this was confirmed by preference values obtained in another session.

PROVIDES GREATER LEEWAY

These applications suggest that the method of magnitude estimation, which typifies the quantitation techniques of ratio-scale measurement, provides a feasible method for assigning numbers to foods, tastes, aromas, textures, etc. These numbers have great flexibility in the ways that they can be manipulated to yield functions relating subjective to physical magnitudes. Knowledge of how two things covary provides the food technologist and the evaluator a far greater leeway in development than does the knowledge that two levels of an ingredient are perceived as being different, or that there is a correlation between two variables, one subjective and the other instrumental.

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