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THE TEXTURE PROFILE: ITS FOUNDATIONS AND OUTLOOK

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Abstract. The origins of the Texture Profile are traced from antecedent developments both in food science and in psychology. A variety of theoretical underpinnings of the Profile are considered: (1) selection of texture variables, (2) problem of standards in texture, (3) appropriate rules for measuring psychological magnitudes, (4) appropriate sensory-instrumental functions, (5) combination rules whereby the observer combines different texture attributes and relates each attribute to a linear combination of others, and (6) interaction between users of the Texture Profile. In each of the above, the underlying assumptions are discussed and possible modifications are suggested in order to generalize the profile procedure.

1. Introduction

In the history of sensory analysis profiling procedures derive from two sources: substantive and theoretical. The texture profile is no exception. Its substantive base is well known – the need for a series of scales and reference stimuli which cover the range of texture properties that are commonly encountered in the sensory analysis of foods. This paper concerns some of the theoretical bases upon which the texture profile is grounded (especially those that are historic or pertain to the theory of sensory measurement), as well as some developments that might ensue in light of our understanding of sensory measurement and its potential.

Profiling the attributes of foods (or, in fact, any complex stimuli) is not a new operation to workers in sensory science. At the turn of the Twentieth Century the American psychologist, Edward Bradford Titchener (1898) founded the school of psychology known as Structuralism. A major tenet of this school was that the mechanisms of sensation and perception could be best understood by instructing the observer to introspect upon his sensations and impressions. Rather than acting as an integrating instrument who attached meaning to his impressions, the observer was cautioned to report only the immediate sensations that he encountered. A room full of objects would be reported as a series of patches of different colors, rather than as a collection of different furniture pieces. This early school of psychology fertilized a series of studies that dealt with the aspects of tactile perception. Studies of the *sensory constitution* of wetness, oiliness and hardness (see Harper, 1974) sought to reduce these complex impressions to sensations of pressure, temperature, etc. All of these studies, it should be stressed, were non-quantitative, and relied solely upon the verbal report from the observer.

Simultaneously with the developing psychology of sensory functioning, there arose a field of psychology known as sensory measurement whose aim was to attach numbers to stimuli according to well defined rules. Psychologists of the 1920's and 1930's became interested in the quantitative properties of sensation, and sought repeatedly

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to develop measurement systems both for physical stimuli (with referents in the environment that could be checked by instruments) and for non-physical ones (without external referents). The pioneering work of Thurstone (1927) demonstrated that scales could be developed for psychology that had interval properties, much like the mathematical properties of the Fahrenheit and Centigrade scales of temperature. At that time, research was in full swing on the development of rating scales. Rating scales (or category scales) require the individual to assign numbers to stimuli on the assumption that differences between ratings reflect sensory distances.

The rapidly developing field of sensory measurement was given an impetus by the observations of S. S. Stevens, a psychologist at Harvard University. Stevens (1946), in a now historic paper, set forth a review of the various types of measurements that could be made, ranging from simply classifying objects (nominal scaling) to rank ordering them (ordinal scaling), and on upwards to assigning numbers to them that reflected distances (interval scaling; like Fahrenheit, Centigrade) or ratios (ratio scaling; like the Kelvin scale).

Today, the majority of sensory analyses relying upon rating scales are confined to interval-scale measurements. The typical scales, used both for scientific studies of texture (or of taste, smell, etc.) and for large scale panel evaluation for acceptability, and even for quality control, comprise a series of ordered categories of magnitude (usually 7 or 9 categories; see Abbott, 1973 for a list of the different scales used in texture assessment).

The Texture Profile, proposed a decade ago by Szczesniak (Szczesniak, 1963; Szczesniak *et al.*, 1963; Brandt *et al.*, 1963) fits into the history of both sensory and perceptual psychology and the developing science of sensory evaluation. The Profile represents one outcome of the marriage of introspectionism and measurement, and one might speculate that without the impetus of the food industry the Texture Profile might eventually have emerged from a psychology laboratory, lacking only the strict set of standards that make the Profile useful for widespread applications. The Profile was shaped in its fine points by the requirements of the food industry for standardized measurements, and for repeatibility that maintains across laboratories, across products and over time.

At the same time as the Texture Profile was gaining popularity, the field of odor perception was similarly being considered by a team of scientists in the United Kingdom, under the direction of R. Harper (Harper *et al.*, 1968a, b). The odor profile that subsequently emerged possesses many of the characteristics of the Texture Profile: emphasis on a limited number of descriptors (c. 44), emphasis on a standard series of odorants to represent qualities (or at least a set of odor references), and a desire to standardize the measurement operation by an easily used interval scale (0–5). It is quite possible that the history of science was repeating itself with the odor profile of Harper *et al.* (1968a). Since, however, the principle impetus was an understanding of odor classification schemes, as well as the use of the odor profile for industrial problems, the odor profile did not become as rigidly standardized in the early stage of its development.

2. Some Theoretical Aspects of the Texture Profile

Implicit in the constitution and operation of the Texture Profile are a number of assumptions about how sensory magnitudes are to be measured, conjectures about relations among texture variables, and suggestions about what the profile can do. The remaining part of this paper concerns several aspects of the profile, and discusses historical perspectives and outlooks for future application.

2.1. Selection of variables

As with many other perceptual domains that have many stimuli and a variety of word descriptors which evolved from common use, texture might be likened to what William James called a 'blooming, buzzing confusion'. The observer may attend to numerous aspects of a food, and in texture he can differentiate a variety of different attributes. Some attributes may be more salient than others; the hardness of a carrot probably is more salient than its flexibility. A major task is to sort out from the array of sensory impressions those basic dimensions to be attended to by the panelist. Szczesniak (1963) has labelled these salient characteristics as (a) mechanical; (b) geometrical; (c) other (e.g., moisture, fat content) etc. In addition, some terms used to describe texture are considered primary, whereas others are called secondary, because they can be described by two or more primary terms.

Distinctions between the concept of 'primary' vs 'secondary' (or perhaps a fundamental dimension vs a derived dimension) have led to considerable research in psychology. For instance, in many studies of intelligence, a variety of psychological tests have been used. Each test presumably contains within it varying proportions of several attributes related to intelligence. The same multiplicity holds for texture as well – each of the texture terms probably contains within it different amounts of several 'fundamental' attributes. As a result, each descriptor term in texture, just like each test in an IQ battery, is some combination of a variety of more basic (and perhaps unnamable) 'primaries'. Perhaps no descriptor term relates to a 'pure' texture attribute, but rather each term is a mixture of primaries, to a greater or lesser degree.

A variety of multivariate analyses have attempted to reduce such phenotypical melanges of 'primaries' to their constituents. Factor analysis (Harman, 1967) is the most important. A prime assumption of factor analysis is that each texture term (or each IQ test in the battery) is a linear combination of a series of 'primaries'. The number of these primaries is always smaller than the number of tests or descriptors. The aim of the factor analysis is to be able to describe each texture term by a linear function of the form:

$$T_i = k_1(P_1) + k_2(P_2) \dots k_n(P_n) \quad (1)$$

$$T_j = k_1(P_1) + k'_2(P_2) \dots k'_n(P_n) \quad (2)$$

According to Equation (1), texture descriptor i (T_i) is a linear combination of n primaries. These primaries are mathematical entities – they may or may not have a name, and to determine whether they correspond to any known texture dimension is left to the ingenuity of the experimenter. However, they are selected so that they provide the best-fitting linear equations, and account for the variability in the ratings. In terms of linear algebra, these primaries 'span the space', for they are orthogonal vectors. The weighting factors k_1 and k'_1 need not be equal, and Equations (1) and (2) show that two different descriptors may be simply different combinations of the same primary dimensions.

Because the technique of factor analysis reduces a series of descriptors to a few primaries, it can be used as a more 'objective' way of selecting variables for the Texture Profile. Its use frees the scientist from the label of subjectivism in selection. The dimensions that derive from the analysis are 'independent' of each other, and account for the wide range of descriptors by means of appropriate linear combinations. The study of Yoshikawa *et al.* (1970) suggested the following seven basic dimensions: hard-soft, cold-warm, oily-juicy, elastic-flaky, heavy, viscous, and smooth. In contrast, the Texture Profile postulates five basic parameters; hardness, cohesiveness, viscosity, springiness, and adhesiveness. Three secondary parameters, fracturability, chewiness and gumminess can be derived from combinations of the primaries. Another study by Yoshida (1968) concerned the dimensions of texture that could be extracted from tactile evaluation of 25 different samples of materials that were of different textures, sizes and shapes. The materials included metals, cloths, sandpapers, and a variety of objects with varying texture. Four basic dimensions emerged from the scaling; heaviness, coldness, smoothness, and hardness.

In future developments of the Texture Profile it may prove useful to consider procedures of data reduction like factor analysis, or multidimensional scaling (Kruskal, 1964), which extract basic dimensions. The analysis reveals the interrelations among the descriptors, and permits the selection of relatively uncorrelated ones. At its best, the factor analysis procedure specifies the nature of the relation between different texture descriptors, and allows for the prediction of responses to one descriptor from responses to other, correlated descriptors.

2.2. The Problem of Standards

Some of the main problems in the implementation of the Texture Profile on a scientific basis is the lack of reproducibility of primary texture standards. This problem is more acute in the area of texture than in flavor where certain organic compounds could be used as standards of primary notes. As an example of the problem of reproducibility one can consider the variability, due to seasonal variation and other factors, of carrots which are used in the hardness scale as number 7.

This scale ranges from value 1 for cream cheese to value 9 for rock candy, and the foods can be cited to illustrate a different problem which refers to 'primary' properties. Each food, besides possessing 'hardness', also has a certain degree of 'fracturability' and other texture attributes, which can modify the 'hardness' attribute to a different extent and in this way distort the scale. The success with the latter problem depends on the selection of foods where the important attribute is overriding, in its prominence, all the others. This, for example, is approximated with the standards in the viscosity scale ranging from value 1 for water to value 8 for condensed milk. The only objection to this scale could probably be the use of the word viscosity, which is a well-defined physical property. (Could consistency be more appropriate?)

If the scale shifts, then the entire profile can be offset, and there is no way of knowing this, unless one makes certain independent mechanical measurements. In the case of carrot, for example, one can determine the modulus of elasticity or the ultimate strength, to check whether there is a change between a previously used standard and the present one. But are any of these measurements representative of what the consumer calls hardness?

Here again we face the same difficulty of attempting to express a complicated sensory response in terms of mechanical measurements, independent of the human being. Since we do not know actually whether any of these measurements expresses 'hardness', ideally one should run a complete characterization of the material, on the premise that if two samples are rheologically the same then they should be sensorially the same as well. In the world of engineering materials, such as metals and plastics, the use of a similar metal or plastic sample as a standard is justified on the basis of the laws of physics. Likewise, the scientific basis of the Texture Profile could be strengthened in the future if simulated foods are used as standards (e.g , texturized proteins) to typify the textural behavior of the natural food. The technology of these simulated foods is advancing rapidly to the point where it could benefit such an endeavor, in the same way that pure chemicals used as standards can benefit the flavor field.

2.3. Measurement of magnitudes

As it is constituted, the Texture Profile uses category or interval scaling, in which the zero point of texture magnitude is not defined for any attribute. Thus, experimenters cannot state whether one perceived viscosity is twice that of another, or the hardness of one biscuit is one sixth that of the standard. They can say that one biscuit is two units harder than another, however.

For applications, interval scaling, (the weaker form of sensory measurement) is useful on two counts. First, it is easily implemented. Observers find it easy to use a sensory scale that comprises a fixed number of points (the so-called 'category scale' of magnitude), and this type of interval scaling is the most popular type of sensory assessment procedure. It is easy to understand and the endpoints allow the observers a degree of confidence about the location of his ratings inside. Second, the fixed categories and a series of physical standards that correspond to each of the categories provide a useful tool for quality control. The observer need not act as a measuring instrument to provide numerical outputs, but rather he merely has to act as a balancing instrument, who matches a current product under investigation against a series of fixed references. His response is simply the statement 'match' or 'no match'. For quality control, therefore, the Texture Profile uses the category scales both as a measure of magnitude, and as a classification procedure (yes-no classification, or match-no-match).

For continued use of the Texture Profile as a measuring instrument, it may eventually prove useful to adopt ratio-scaling methods, in place of interval scaling. This stronger form of measurement is to be preferred because of the following reasons:

(a) Nature measures magnitudes along a ratio scale, not along an interval scale. In mechanics, and in physics in general, quantities are measured so that the ratios of measurements are meaningful. The Fahrenheit and Centigrade scale are useful interval scales, but for adequate prediction of reactions the Kelvin scale, with its absolute zero point and ratio properties, is preferred. Similarly, for appropriate measurement of sensory and perceptual responses, and for eventual use of the Texture Profile for complex predictions, the level of measurement of sensory responses should be at the level of the ratio scale.

(b) The interval scale requires an arbitrary zero, whereas the ratio scale has an absolute value, and measurements may be expressed in percentage values (dimensionless numbers). The relative magnitudes of two numbers expressed in a ratio is immediately known, whereas the difference of two numbers on an interval scale must be compared with the size of the unit of the scale. No convenient percentage statistic exists for interval scale measurement. A difference of 3 poises is much larger than a difference of 3 centipoises.

(c) If the Texture Profile is to be used for exploring subjective-instrumental relations, it would be ideal for the level of measurement to be commensurate in both domains, especially when functional relations are sought between sensory responses and mechanical properties. Often, the functional relation can prove useful, either for understanding the workings of man's sensory system as it applies to the appreciation of texture (i.e., an understanding of our tactile and kinaesthetic senses), or for developing process-control limits for monitoring the texture of foods being produced. Currently, the functions used are logarithmic equations in which ratios of physical magnitudes are mapped into sensory differences (or intervals). It would be useful to develop equations in the Texture Profile that relate percentage changes in a sensory domain to percentage changes in a physical (or mechanical) domain.

2.4. Types of Sensory-Instrumental Functions

The above Texture Profile uses logarithmic functions ($S=k(\log I)$) to relate instrumental measures (or mechanical properties, I) to sensory responses (S). If both the sensory and the instrumental measures are made so that they have ratio-scale properties, then power functions, rather than logarithmic functions, are the appropriate sensory-instrumental functions (Aczél, 1966).

In recent years, direct estimation of sensory magnitudes on a variety of continua, ranging from the length of lines to the loudness of tones, and onwards to the hardness of rubber samples, have yielded simple power functions of the form $S=kI^n$ (S=sensory magnitude, obtained from direct numerical estimation of intensity, I=instrumental magnitude, measured by 'objective' means). The laboratory procedure that produces many of these empirical power functions is known as *magnitude estimation*. The observer is presented with a series of stimuli of different magnitudes and asked to assign numbers to the stimuli with the restriction that ratios of numbers are to reflect perceived ratios of magnitude. In texture, a variety of sensory attributes have been scaled and exponents (n) determined: Stevens and Guirao (1964) and Moskowitz (1972) reported that for the estimation of viscosity of silicone oils and liquid solutions and suspensions of vegetable gums, respectively, the exponent varied between 0.4 and 0.5. Stevens and Harris (1962) scaled the apparent roughness and smoothness of sandpaper and reported an exponent of 1.5. Two studies of hardness have been reported. In the first, Harper and Stevens (1964) scaled the hardness of different samples of rubber that varied in the force/indentation ratio and reported an exponent of 0.7. In the second, Moskowitz *et al.* (1974) scaled the hardness (and crunchiness) of small, rectangular space cubes of different flavors that were fabricated for the NASA space program and found exponents around 0.4–0.6 for hardness and crunchiness as a function of the modulus of elasticity.

The exponent of the power function is an important parameter, not only for describing the slope of the linearized power function in log-log coordinates (viz. $S=kI^n$ becomes $\log S=n \log I+\log k$), but because it indicates how rapidly subjectively estimated magnitudes grow with physically measured magnitudes. If the exponent equals 1, then the ratios of sensory estimates equal the ratios of physical magnitudes. When the exponent is less than 1.0, the ratios of sensory estimates are correspondingly less than the ratios of physical magnitudes. For example, in the case of viscosity, a 10:1 increment in centipoises becomes a $(10/1)^{0.5}=3.2:1$ increment in perceived viscosity. On the other hand, when the exponent is greater than 1.0, subjective ratios are greater than the ratios of physical magnitudes. For roughness, an increase in the grit size of 10:1 is perceived as a $(10/1)^{1.5}=32:1$ change in subjective roughness. In all cases, however, the power function transforms ratios in one domain (physical, mechanical) to ratios in the other (subjective, perceptual).

2.5. Combination Rules of Texture Attributes

As it is constituted, the Texture Profile is an instrument used for describing the nuances of texture in foods. The act of profiling is initially one of nominal measurement (classification), and subsequently the attachment of numbers to the various attributes according to rules. It is quite possible and desirable to develop a profiling system that is dynamic, so that combinations of known texture variables can lead to still further texture variables that are useful.

Szczesniak *et al.* (1963) suggested a number of derived texture variables, that could be construed as products or ratios of 'primary' variables. These include fracturability, chewiness and gumminess. From a consideration of the General Foods Texturometer, the instrumental analog to the Texture Profile, whose readings can yield 'instrumental' correlates of the profile, Friedman *et al.* (1963) suggested that chewiness could be expressed (instrumentally) as hardness × cohesiveness × springiness, whereas gumminess could be expressed as the product of hardness × cohesiveness. Since instrumental measures, even of the integrative type (viz. that of the Texturometer) lie on a ratio scale of magnitude, these products are mathematically correct. Were the sensory correlates of the Texturometer also to be measured along a ratio scale, one might then be able to derive relations among sensory variables from relations among their physical correlates. These correlates might be simple mechanical properties, well defined by the laws of physics, or complex, integrative ones that are developed in the course of imitating the response of the observer. In equation form, if the relation: Chewiness = = Hardness × Cohesiveness × Springiness holds for instrumental measurement, then perhaps; S(Chewiness) = S(Hardness) × S(Cohesiveness) × S(Springiness) [S(Chewiness) = sensory chewiness of perceived or perceived or subjective chewiness]. This conjecture may be tested by first determining ratio scale values for both instrumental and subjective chewiness, hardness, cohesiveness and springiness, respectively, and then multiplying all instrumental measures, and separately multiplying all subjective measures. The two products ought to be commensurate, or at least one should be transformable to the other by a simple function.

In the same vein, if one assumes that the observer 'carries around' with him correlates of texture, which are tapped by the Texture Profile, then it may be possible through experimentation to determine the laws by which the observer combines the separate subjective texture correlates. Does he combine them in manners consonant with physics? Does he combine pairs of triples (or higher *n*-tuples) of correlates in new ways to derive subjective properties consonant with physics, but hitherto unsuspected?

A program to discover the law of 'subjective texture' might consist of profiling many foods (or other stimuli) along a variety of texture descriptors. As few as ten, or as many as one hundred or more descriptors might be used, and a large range of foods should be used. By appropriate instructions, the observer could be instructed to assign to each food a number to reflect the degree to which a specific texture attribute (e.g., hardness) is present in the food (e.g., apple). These numbers would be assigned according to the rules for ratio scaling, and all number assignments across stimuli and texture attributes would have to be commensurate. (This means that a 100 for hardness and a 100 for viscosity would be sensorially equal, although they pertain to different stimuli, and to different classes of attributes). The output of the experiments would consist of a matrix of **m** texture attributes and **n** stimuli. By appropriate regression analyses, one could derive relations among the subsets of the **m** texture attributes. For example, across the **n** foods, hardness and springiness could be related by a simple power function: $H = k'(E^{p1})(C^{p2})(B^{p3})$ or $\log H = \log k' + p_1(\log E) + p_2(\log C) + p_3(\log B)$. This equation is an example of a rule of combination whereby an unsuspected relation among texture attributes could be uncovered through sensory measurement.

2.6. Interactions between users of the texture profile

The foregoing discussion traced the development of the Texture Profile from its progenitors in psychology and food science, through its implementation as a standard assessment technique, and suggested potentially fruitful avenues of further exploration. Another point to be stressed is the potential of the Texture Profile as a *dynamic* *instrument* that reveals as much about the texture perception of the individual observer as it does about the food being profiled. However, much work needs to be done to bring this transformation about.

Recognition that the profile is a fluid entity is paramount. Workers in basic research tend to ignore systems for profiling and measurement that have become standardized, preferring instead to concentrate their visions upon uncharted vistas. Consequently, they fail to provide the needed impetus to improve existing measurement systems. Simultaneously, food technologists working with profiling systems that have adequately performed in the past are loathe to venture out into the uncharted regions, preferring instead to rely upon trusted methods that are adequate to their present needs, but which may not hold the capability to answer future requirements. Consequently, the food technologist fails to call out for the needed assistance to improve the profile. We believe that the approaches outlined in this paper may provide part of the necessary program of research to transform the Texture Profile into a more dynamic procedure that contains within it the seeds of its own transformation that allows it to respond to varying needs of different users. We recognize that the Texture Profile plays a dual role; on one hand it is required for quality control and routine sensory measurements of texture, but on the other hand it reflects implicitly our concept of how human observers assess texture. Each aspect of this duality can be used to improve the other. Applied research with the profile can modify its constitution just as readily as basic research can alter the rules of texture measurement and illustrate the laws of subjective combinations of texture attributes.

3. Concluding Remarks

The engineering characteristics of the mechanical properties of the food can be determined by established procedures of rheology. This is one side of the equation. The other side is the descriptive terms and ratings on these terms which the consumer uses in the realm of 'texture'. There is not yet a final, universally acceptable equation to relate these two parts. What, for example, does the modulus of elasticity or ultimate strength mean in terms of sensory perception? Are they parts of tenderness or crispiness, and in what quantitative way? Whereas much is known from the science of rheology on methods to characterize the food as an engineering material, there has been much ambiguity and overlapping of descriptions in trying to define texture in sensory terms. The Texture Profile is the first serious attempt to bring 'order into the chaos' by analyzing the sensory attributes into individual descriptive terms and assigning numbers to these terms. It is also an attempt to bridge the two sides of the equation. This is done by using 'integrative' complex entities, such as cohesiveness, adhesiveness etc, (which the method tries to measure by both the machine and the human subject), instead of engineering, rheologically defined properties.

The Texture Profile has contributed substantially in quality control and development work. It has given the plant manager a practical tool to define the sensorially perceived textural attributes of the food, and to follow the variations with time (drifting) of quality. It has shown the way for further development and refinements, either on the basis of the same integrative approach or, most preferably, in terms of rheological, universally accepted measurements to be correlated with sensory descriptions of texture.

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