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FIFTH EDITION

Sensory Evaluation Techniques

Morten C. Meilgaard
Gail Vance Civille • B. Thomas Carr

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Dedication

to

Manon, Frank, and Cathy

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PREFACE TO THE FIFTH EDITION

How does one plan, execute, complete, analyze, interpret, and report sensory tests? The practices and recommendations in this book are intended to cover all of those phases of sensory evaluation. The text is meant as a personal reference volume for food scientists, research and development scientists, cereal chemists, perfumers, and other professionals working in industry, academia, or government who need to conduct good sensory evaluation. The book should also supply useful background to marketing research, advertising, and legal professionals who need to understand the results of sensory evaluation. It could also give a sophisticated general reader the same understanding.

Because the first edition was used as a textbook at the university and professional level, partly in courses taught by the authors, the second, third, fourth, and fifth editions incorporate a growing number of ideas and improvements arising from questions from students. The objective of the book is now twofold. First, as a "how to" text for professionals, it aims for a clear and concise presentation of practical solutions, accepted methods, standard practices, and some advanced techniques. Second, as a textbook for courses at the academic level, it aims to provide just enough theoretical background to enable the student to understand which sensory methods are best suited to particular research problems and situations and how tests can best be implemented.

The authors do not intend to devote text and readers' time to resolving controversial issues, but a few had to be tackled. We take a fresh look at all statistical methods used for sensory tests, and we hope you like our straightforward approach. The second edition was the first book to provide an adequate solution to the problem of similarity testing. This was adopted and further developed by ISO TC34/SC12 on Sensory Evaluation, resulting in the current "unified" procedure (Section 7.2) in which the user's choice of α- and β-risks defines whether difference or similarity is tested for. Another "first" is the unified treatment of all ranking tests with the Friedman statistic, in preference to Kramer's tables.

Chapter 12 on the Spectrum™ method of descriptive sensory analysis, developed by Civille, has been expanded. The philosophy behind Spectrum is threefold: (1) the test should be tailored to suit the objective of the study (and not to suit a prescribed format); (2) the choice of terminology and reference standards should make use not only of the senses and imagination of the panelists but also of the accumulated experience of the sensory profession as recorded in the literature; and (3) a set of calibrated intensity scales is provided, which permits different panels at different times and locations to obtain comparable and reproducible profiles. The chapter contains full descriptive lexicons suitable for descriptive analysis of a number of products, for example, cheese, mayonnaise, spaghetti sauce, white bread, cookies, and toothpaste. There are updated intensity scales for attributes such as crispness, juiciness, and some common aromatics; and two training exercises.

The authors wish the book to be cohesive and readable; we have tried to substantiate our directions and organize each section so as to be meaningful. We do not want the book to be a turgid set of tables, lists, and figures. We hope we have provided structure to the methods, reason to the procedures, and coherence to the outcomes. Although our aim is to describe all tests in current use, we want this to be a reference book that can be read for understanding as well as a handbook that can serve to describe all major sensory evaluation practices.

The organization of the chapters and sections is also straightforward. Chapter 1 lists the steps involved in a sensory evaluation project, and Chapter 2 briefly reviews the workings of our senses. In Chapter 3, we list what is required of the equipment, the tasters, and the samples, while in Chapter 4, we have collected a list of those psychological pitfalls that invalidate many otherwise good studies. Chapter 5 discusses how sensory responses can be measured in quantitative terms. In Chapter 6, we provide guidelines for selecting the appropriate sensory approach. Chapter 7 describes all the common sensory tests for difference—the triangle, duo–trio, and so on—and Chapter 8 outlines the various attribute tests, such as ranking and numerical intensity scaling. New to the fifth edition is a discussion of tetrad testing, both specified and unspecified, which spans both Chapters 7 and 8. Thresholds and just-noticeable differences are briefly discussed in Chapter 9, followed by what we consider the main chapters: Chapter 10 on the selection and training of panelists, Chapters 11 and 12 on descriptive testing, and Chapter 13 on affective tests (consumer tests). All the descriptive references have been reviewed and revised for the Spectrum references in Chapter 12. Chapter 13 defines in detail several classic qualitative and quantitative methods for testing with consumers and includes a substantial review of Internet research. Chapter 17 offers an update to the existing texts on the application of sensory to quality control. This refined and streamlined adaptation provides more practical approaches for setting up rigorous in-plant sensory tests that match the organization's skill set and resources. Chapter 18 provides an introduction to and discussion of some of the latest methods used by sensory researchers in many consumer products companies.

The body of text on statistical procedures is found in Chapters 14 and 15, but, in addition, each method (triangle, duo–trio, etc.) in Chapters 7 and 8 is followed by a number of examples showing how statistics are used in the interpretation of each method. Basic concepts for tabular and graphical summaries, hypothesis testing, and the design of sensory panels are presented in Chapter 14. We refrain from detailed discussion of statistical theory, preferring instead to give examples. Chapter 15 discusses multifactor experiments that can be used, for example, to screen for variables that have large effects on a product, to identify variables that interact with each other in how they affect product characteristics, or to identify the combination of variables that maximize some desirable product characteristic, such as consumer acceptability. Chapter 15 also contains a discussion of multivariate techniques that can be used to efficiently summarize large sets of sensory data; to identify relationships among responses that might otherwise go unnoticed, especially those involving instrumental, sensory, and consumer data; and to group respondents or samples that exhibit similar patterns of behavior. Chapter 15 also includes a discussion of Thurstonian scaling, which can be used to study differences among products and to uncover the decision processes used by assessors during their sensory evaluations.

New in the fifth edition, Chapter 20 offers some challenges to students in sensory evaluation. The questions are real life and ask students to think through complete sensory research questions. Answers provide some feedback to students who are using this book to make decisions.

At the end of the book, the reader will find guidelines for reporting results, plus the usual glossaries, indexes, and statistical tables.

With regard to terminology, the terms "assessor," "judge," "panelist," "respondent," "subject," and "taster" are used interchangeably, as are "he," "she," and "(s)he" for the sensory analyst (the sensory professional, the panel leader) and for individual panel members.

Morten Meilgaard
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AUTHORS

Gail Vance Civille is president of Sensory Spectrum, Inc., a management consulting firm involved in the field of sensory evaluation of foods, beverages, pharmaceuticals, paper, fabrics, personal care, and other consumer products. Sensory Spectrum provides guidance in the selection, implementation, and analysis of test methods for solving problems in quality control, research, development, production, and marketing. She has trained several flavor and texture descriptive profile panels in her work with industry, universities, and government.

As a course director for the Center for Professional Advancement and Sensory Spectrum, Ms. Civille has conducted several workshops and courses in basic sensory evaluation methods as well as in advanced methods and theory. In addition, she has been invited to speak to several professional organizations and universities about various facets of sensory evaluation. She is a founding member and former chair of the Society of Sensory Professionals.

Ms. Civille has published books and articles on general sensory methods, as well as sophisticated descriptive flavor and texture techniques. A graduate of the College of Mount Saint Vincent, New York, for which she serves on the Board of Trustees, Ms. Civille earned a BS degree in chemistry and began her career in product evaluation with the General Foods Corporation.

B. Thomas Carr is principal of Carr Consulting, a research consulting firm that provides project management, product evaluation, and statistical support services to the food, beverage, personal care, and home care industries. He has over 30 years of experience in applying statistical techniques to all phases of research on consumer products. Prior to founding Carr Consulting, Mr. Carr held a variety of business and technical positions in the food and food ingredient industries. As director of contract research for NSC Technologies/NutraSweet, he identified and coordinated outside research projects that leveraged the technical capabilities of all the groups within NutraSweet research and development, particularly in the areas of product development, analytical services, and sensory evaluation. Prior to that, as manager of statistical services at both NutraSweet and Best Foods, Inc., he worked closely with the sensory, analytical, and product development groups on the design and analysis of a full range of research studies in support of product development, quality assurance/quality control, and research guidance consumer tests.

Mr. Carr is a member of the US delegation to the ISO TC34/SC12. He is actively involved in the statistical training of scientists and has been an invited speaker to several professional organizations on the topics of statistical methods and statistical consulting in industry. Since 1979, Mr. Carr has supported the development of new food ingredients, consumer food products, and over-the-counter drugs by integrating the statistical and sensory evaluation functions into the mainstream of the product development effort.

This has been accomplished through the application of a wide variety of statistical techniques, including design of experiments, response surface methodology, mixture designs, sensory/instrumental correlation, and multivariate analysis.

Mr. Carr received his BA degree in mathematics from the University of Dayton and his master's degree in statistics from Colorado State University.

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IN MEMORY OF MORTEN MEILGAARD, D.SC.

From the mid-1980s, when we started this venture, now commonly called the *SET*, we were impressed with the leadership, gentility, intelligence, and doggedness of our lead author, Morten Meilgaard. Although we dreaded the large manila envelopes with the Stroh's logo—because it meant a detailed worksheet and timeline for "next steps"—we knew Morten was taking on as much, if not more, than we were. Because he led by example and was meticulous and precise in his own contributions, we knew we needed to up our game to match his. Although we worked on this text for over 20 years until his passing in 2009, we *never* had "words" or contentious disagreements. It was hard work, but the culture and tone were always agreeable, friendly, *and* productive. We are not alone in branding Morten a gentleman and scholar. All who knew him offer a similar description. It was our pleasure to watch Morten work, challenge ideas, formulate solutions, and keep us on task and on time. Morten remains listed as the first author on this text because he is this text's primary author.

Morten C. Meilgaard, M.Sc., D.Sc., F.I. Brew, was visiting professor (emeritus) of sensory science at the Agricultural University of Denmark and vice president of research (also emeritus) at the Stroh Brewery Co., Detroit, MI. He studied biochemistry and engineering at the Technical University of Denmark, to which he returned in 1982 to receive a doctorate for a dissertation on beer flavor compounds and their interactions. After 6 years as a chemist at the Carlsberg Breweries, he worked from 1957 to 1967 and again from 1989 as a worldwide consultant on brewing and sensory testing. He served for 6 years as director of research for Cervecería Cuauhtémoc in Monterrey, Mexico, and for 25 years with Stroh. At the Agricultural University of Denmark, his task was to establish sensory science as an academic discipline for research and teaching.

Dr. Meilgaard's professional interest was the biochemical and physiological basis of flavor, and more specifically the flavor compounds of hops and beer and the methods by which they can be identified, namely, chemical analysis coupled with sensory evaluation techniques. He had published over 70 papers and developed the beer wheel lexicon that is still used in the beer industry. He was the recipient of the Schwarz Award and the Master Brewers Association Award of Merit for studies of compounds that affect beer flavor. He was founder and past president of the Hop Research Council of the United States and was past chairman of the Scientific Advisory Committee of the US Brewers Association. For 14 years, he was chairman of the Subcommittee on Sensory Analysis of the American Society of Brewing Chemists. He had chaired the US delegation to the ISO TC34/SC12 Subcommittee on Sensory Evaluation. Dr. Meilgaard died April 11, 2009 and is survived by his sons, Stephen Goodfellow and Justin Meilgaard.

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1

Introduction to Sensory Techniques

1.1 INTRODUCTION

This introduction is in three parts. The first part lists some reasons why sensory tests are performed and briefly traces the history of their development. The second part introduces the basic approach of modern sensory analysis, which is to treat the panelists as measuring instruments. As such, they are highly variable and very prone to bias, but they are the only instruments that will measure what needs to be measured; therefore, the variability must be minimized and the bias must be controlled by making full use of the best existing techniques in psychology and psychophysics. In the third part, a demonstration is provided of how these techniques are applied with the aid of seven practical steps.

1.2 DEVELOPMENT OF SENSORY TESTING

Sensory tests, of course, have been conducted for as long as there have been human beings evaluating the goodness and badness of food, water, weapons, shelters, and everything else that can be used and consumed.

The rise of trading inspired slightly more formal sensory testing. A buyer, hoping that a part would represent the whole, would test a small sample of a shipload. Sellers began to set their prices on the basis of an assessment of the quality of goods. With time, ritualistic schemes of grading wine, tea, coffee, butter, fish, and meat developed, some of which survive to this day.

Grading gave rise to the professional taster and consultant to the budding industries of foods, beverages, and cosmetics in the early 1900s. Literature was developed that used the term *organoleptic testing* (Pfenninger, 1979) to denote the supposedly objective measurement of sensory attributes. In reality, tests were often subjective, tasters too few, and interpretations open to prejudice.

Pangborn (1964) traces the history of systematic "sensory" analysis that is based on wartime efforts to provide acceptable food to American forces (Dove, 1946, 1947) and on the development of the triangle test in Scandinavia (Bengtsson and Helm, 1946; Helm and Trolle, 1946). A major role in the development of sensory testing was played by the

Food Science Department at the University of California at Davis, resulting in the book by Amerine et al. (1965).

Scientists have only recently developed sensory testing as a formalized, structured, and codified methodology, and they continue to develop new methods and refine existing ones. The current state of sensory techniques is recorded in the dedicated journals *Chemical Senses*, *Journal of Sensory Studies*, *Journal of Texture Studies*, *Food Quality*, and *Journal of Cosmetic Studies*; in the proceedings of the Pangborn Symposia (triennial) and the International Sensometrics Group (biannual), both usually published as individual papers in the journal *Food Quality & Preference*; and the proceedings of the Weurman Symposia (triennial, but published in book form, e.g., Martens et al., 1987; Bessière and Thomas, 1990). Sensory papers presented to the Institute of Food Technologists (IFT) are usually published in the IFT's *Journal of Food Science* or *Food Technology.* Papers presented at the Society of Sensory Professionals are typically published in the *Journal of Sensory Studies.*

The methods that have been developed serve economic interests. Sensory testing can develop a level of acceptability for a commodity or help determine the value of a commodity. Sensory testing evaluates alternative courses to select the one that optimizes value for money. The principal uses of sensory techniques are in quality control, product development, and research. They find application not only in the characterization and evaluation of foods and beverages but also in other fields such as household products, environmental odors, personal hygiene products, diagnosis of illnesses, testing of pure chemicals, and so on. The primary function of sensory testing is to conduct valid and reliable tests that provide data on the basis of which sound decisions can be made.

1.3 HUMAN SUBJECTS AS INSTRUMENTS

Dependable sensory analysis is based on the skill of the sensory analyst in optimizing the four factors of such analysis, which we all recognize because they are the ones that govern any measurement (Pfenninger, 1979).

1. *Definition of the problem*: We must define precisely what it is we wish to measure; important as this is in "hard" science, it is much more so with senses and feelings.
2. *Test design*: Not only must the design leave no room for subjectivity and take into account the known sources of bias, but it also must minimize the amount of testing required to produce the desired accuracy of results. Test controls for subjects, site, samples, and sensory methods must be in place (Civille and Oftedal 2012).
3. *Instrumentation*: The test subjects must be selected and trained to give a reproducible verdict; the analyst must work with them until he/she knows their sensitivity and bias in the given situation.
4. *Interpretation of results*: Using statistics, the analyst chooses the correct null hypothesis and the correct alternative hypothesis and draws only those conclusions that are warranted by the results.

Tasters, as measuring instruments, are (1) quite variable over time, (2) very variable among themselves, and (3) highly prone to bias. To account adequately for these shortcomings requires (1) that measurements be repeated, (2) that enough subjects (often 20–50) are made available so that verdicts are representative, and (3) that the sensory analyst respects the many rules and pitfalls that govern panel attitudes (see Chapter 4). Subjects vary innately in sensitivity by a factor of 2–10 or more (Meilgaard and Reid, 1979; Pangborn, 1981) and should not be interchanged halfway through a project. Subjects must be selected for sensitivity and must be trained and retrained (see Chapter 9) until they fully understand the task at hand. The annals of sensory testing are replete with results that are unreliable because many of the panelists did not understand the questions and/or the terminology used in the test, did not recognize the tactile and fragrance parameters in the products, or did not feel comfortable with the mechanics of the test or the numerical expressions used.

For these reasons and others, it is very important for the sensory analyst to be actively involved in the development of the scales and the terminology/lexicons used to measure the panelists' responses. A good scale requires much study, must be based on a thorough understanding of the physical and chemical factors that govern the sensory variable in question, and requires several reference points and thorough training of the panel on that scale. It is unreasonable to expect that even an experienced panelist would possess the necessary knowledge and skill to develop a lexicon that is consistently accurate and precise. Only through the direct involvement of a knowledgeable sensory professional in the development of scales can one obtain descriptive analyses, for example, that will mean the same in 6 months' time as they do today.

1.3.1 Chain of Sensory Perception

When sensory analysts study the relationship between a given physical stimulus and the subject's response, the outcome is often regarded as a one-step process. In fact, there are at least three steps in the process: The stimulus hits the sense organ and is converted to a nerve signal that travels to the brain. With previous experiences in memory, the brain then interprets, organizes, and integrates the incoming sensations into perceptions. Finally, a response is formulated based on the subject's perceptions (Schiffman, 1996).

In dealing with the fact that humans often yield varied responses to the same stimulus, sensory professionals need to understand that differences between two people's verdicts can be caused either by a difference in the sensation they receive because their sense organs differ in sensitivity or by a difference in their mental treatment of the sensation, for example, because of a lack of knowledge of the particular odor, taste, and so on, or because of lack of training in expressing what they sense in words and numbers. Through training and the use of references, sensory professionals can attempt to shape the mental process so that subjects move toward showing the same response to a given stimulus.

A commendable critical review of the psychophysical measurement of human olfactory function (with 214 references) can be found in Chapter 10 of Doty and Laing (2003).

1.4 CONDUCTING A SENSORY STUDY

The best products are developed in organizations where the sensory professional is more than the provider of a specialized testing service. Only through a process of total involvement can he or she be in the position of knowing what tests are necessary and appropriate at every point during the life of a research project. The sensory professional (like the statistician) must take an active role in developing the research program, collaborating with the other involved parties on the development of the experimental designs that ultimately will be used to answer the questions posed. Erhardt (1978) divides the role of the sensory analyst into the following seven practical tasks:

1. Determine the project objective. Defining the needs of the project leader is the most important requirement for conducting the correct test. Were the samples submitted as a product improvement, to permit cost reduction or ingredient substitution, or as a match of a competitor's product? Is one sample expected to be similar or different from others, preferred or at parity, variable in one or more attributes? If this critical step is not carried out, the sensory analyst is unlikely to use the appropriate test or to interpret the data correctly.
2. Determine the test objective. Once the objective of the project can be clearly stated, the sensory analyst and the project leader can determine the test objective: overall difference, attribute difference, relative preference, acceptability, and so on. Avoid attempting to answer too many questions in a single test. A good idea is for the sensory analyst and project leader to record in writing, before the test is initiated, the project objective, the test objective, the specifics of the test, the set of samples, and a brief statement of how the test results will be used.
3. Screen the samples. During the discussion of project and test objectives, the sensory analyst should examine all of the sensory properties of the samples to be tested. This enables the sensory analyst to choose test methods that take into account any sensory biases introduced by the samples. For example, visual cues (color, thickness, sheen) may influence overall difference responses, such as those provided in a triangle test, for example, to measure differences due to sweetness of sucrose versus aspartame. In such a case, an attribute test would be more appropriate. In addition, product screening provides information on possible terms to be included in the score sheet.
4. Design the test. After defining the project and test objectives and screening the samples, the sensory analyst can proceed to design the test. This involves selection of the test technique (see Chapter 6 for general guidelines; see Chapters 7, 8, 9, 11, 12, 13, 17, and 18 for specific guidelines for different sensory techniques); selecting and training panelists (see Chapter 10); designing the accompanying score sheet (ballot, questionnaire); specifying the criteria for sample preparation and presentation (see Chapter 3); and determining how the data will be analyzed (see Chapters 13 and 14). Care must be taken, in each step, to adhere to the principles of statistical design of experiments to ensure that the most sensitive evaluation of the test objective is attained.
5. Conduct the test. Even when technicians are used to carry out the test, the sensory analyst is responsible for ensuring that all the requirements of the test design are met.
6. Analyze the data. Because the procedure for analysis of the data was determined at the test design stage, the necessary expertise and statistical programs, if used, will be ready to begin data analysis as soon as the study is completed. The data

should be analyzed for the main treatment effect (test objective) as well as other test variables, such as order of presentation, time of day, different days, and/or subject variables such as age, sex, geographic area, and so on (see Chapters 14 and 15).

7. Interpret and report results. The initial clear statement of the project and test objectives will enable the sensory analyst to review the results, express them in terms of the stated objectives, and make any recommendations for action that may be warranted. The latter should be stated clearly and concisely in a written report that also summarizes the data, identifies the samples, and states the number and qualification of subjects (see Chapter 16).

The main purpose of this book is to help the sensory analyst develop the methodology, subject pool, facilities, and test controls required to conduct analytical sensory tests with trained and/or experienced tasters. In addition, Chapters 13 and 19 discuss the organization of consumer tests, that is, the use of naïve consumers (nonanalytical) for large-scale evaluations, which are structured to represent the population of the product market. The role of sensory evaluation in the development of advertising claims is also addressed.

The role of sensory evaluation and quality is to provide valid and reliable information to research and development (R&D), production, and marketing in order for management to make sound business decisions about the perceived sensory properties of products. The ultimate goal of any sensory program should attempt to find the most cost-effective and efficient method with which to obtain the most sensory information. When possible, internal laboratory difference or descriptive techniques are used in place of more expensive and time-consuming consumer tests to develop cost-effective sensory analysis. Further cost savings may be realized by correlating as many sensory properties as possible with instrumental, physical, or chemical analyses. In some cases, it may be possible to replace a part of routine sensory testing with cheaper and quicker instrumental techniques.

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2

Sensory Attributes and the Way We Perceive Them

2.1 INTRODUCTION

This chapter reviews (1) the sensory attributes with which the book is concerned, for example, the appearance, odor, flavor, and feel of different products; and (2) the mechanisms that people use to perceive those attributes, for example, the visual, olfactory, gustatory, and tactile/kinesthetic senses and sometimes sound. This chapter is brief, not because it is less important, but because many other books cover in depth the psychological and physiological mechanisms of sensation and perception. The sensory professional is urged to study the references for this chapter (e.g., Amerine et al., 1965; ASTM, 1968; Civille and Lyon, 1996; Lawless and Heymann, 1998; and Stone and Sidel, 2004) and to build a good library of books and journals on sensory perception. Sensory testing is an interdisciplinary science comprised of information and methods adapted from psychology, physiology, statistics, linguistics, medicine, chemistry, physics, sociology, anthropology, and a host of other fields. Experimental designs need to be based on a thorough knowledge of the physical, chemical, and psychophysiological factors behind the attributes of interest. Results of sensory tests often have several possible explanations; therefore, when interpreting these results, it is important to consider new knowledge about the senses, the true nature of product attributes, probability and risk management, and consumer behavior.

2.2 SENSORY ATTRIBUTES

The attributes of a food item are typically perceived in the following order:

- Appearance
- Odor/aroma/fragrance
- Consistency and texture
- Flavor (aromatics, chemical feelings, basic tastes)

However, in the process of perception, most or all of the attributes overlap; that is, the subject receives a jumble of near-simultaneous sensory impressions, and without training, he or she will not be able to provide an independent evaluation of each. This section gives examples of the types of sensory attributes that exist in terms of the way that they are perceived and the words or phrases that may be used to describe them.

In this book, *flavor* is the combined impression perceived via the chemical senses from a product in the mouth and does not include appearance and texture. The term *aromatics* is used to indicate those volatile constituents that originate from food in the mouth and are perceived by the olfactory system via the posterior nares.

2.2.1 Appearance

As every shopper knows, the appearance of the product and/or the package often is the only attribute on which the decision to purchase or consume a product is based. Hence, people become adept at making wide and risky inferences from small clues, and test subjects will do the same in the booth. It follows that the sensory analyst must pay meticulous attention to every aspect of the appearance of test samples (Amerine et al., 1965, 399; McDougall, 1983; Lawless and Heymann, 2010) and often must attempt to obliterate or mask much of it with lighting, opaque containers, and so on. Although it is easy to "justify" letting the panel see the product because "that is the way it will be used," this justification is deceptive. That interaction may be critical if consumer understanding is desired but is misleading if it shrouds the truth about the sensory properties of the product.

General appearance characteristics are listed below, and an example of the description of appearance with the aid of scales is given in Appendix 12.1.

Color	A phenomenon that involves both physical and psychological components—the perception by the visual system of light of wavelengths 400–500 nm (blue), 500–600 nm (green and yellow), and 600–800 nm (red), commonly expressed in terms of the hue, value, and chroma of the Munsell color system. The evenness of color, as opposed to an uneven or blotchy appearance, is important. Deterioration of food is often accompanied by a color change. Good descriptions of procedures for the sensory evaluation of appearance and color are given by Clydesdale (1984), McDougall (1988), and Lawless and Heymann (1998). Because color can be impacted by the surroundings, the lighting, and the angle of the observer, these need to be standardized when testing.
Size and shape	The length, thickness, width, particle size, geometric shape (square, circular, etc.), and distribution of pieces, for example, of vegetables, pasta, specks, and so on. Size and shape often are key indicators of quality aspects of the product and also may indicate defects (Kramer and Twigg, 1973; Gatchalian, 1981).

Surface texture	The dullness or shininess of a surface; its roughness versus evenness; and its appearance of wetness, dryness, smoothness, crust, or depth may be key characteristics, either of the product, particularly for many nonfood products such as paint, personal care products (e.g., nail polish or lipstick), and so on; or for the effects of the product, such as that of shampoo or conditioner on hair.
Clarity	The haze (Siebert et al., 1981) or opacity (McDougall, 1988) of liquids, gels, or solids or the presence or absence of particles of visible size. Similarly, the ability to see multiple layers in some products such food, personal care products, polishes, and so on can be an indication of other sensory attributes.
Carbonation	For beverages with gas, the degree of effervescence observed (during pouring or after sitting for a specified period) (Descoins et al., 2006).

2.2.2 Odor/Aroma/Fragrance

The odor of a product is detected when its volatiles enter the nasal passage and are perceived by the olfactory system. The term *odor* or one of its variations is used when the volatiles are sniffed through the nose. Aroma is the odor of a food product, and fragrance is the odor of a perfume, cosmetic, or personal or household good. As mentioned earlier, aromatics are the volatiles perceived by the olfactory system from a substance in the mouth. The term smell is not used in this book because it has a negative connotation (e.g. malodor) to some people, whereas to others, it is the same as odor.

The amount of volatiles that escape from a product is affected by the temperature as well as the nature of the compound. The vapor pressure of a substance exponentially increases with temperature according to the following formula:

$$\log p = -0.05223a / T + b \tag{2.1}$$

where:

p is the vapor pressure in mmHg
T is the absolute temperature ($T = t$°C+273.1)
a and b are substance constants that can be found in handbooks (Howard, 1996)

Volatility also is influenced by the condition of a surface; at a given temperature, more volatiles escape from a soft, porous, humid surface than from a hard, smooth, dry one.

Many odors are released only when an enzymic reaction takes place at a freshly cut surface (e.g., the smell of an onion). Odorous molecules must be transmitted by a gas, for example the atmosphere, water vapor, or an industrial gas; and the intensity of the perceived odor is determined by the proportion of odorous molecules in the gas that come into contact with the observer's olfactory receptors (Laing, 1983).

Sensory professionals continue to be challenged by the sorting of fragrance/aroma sensations into identifiable terms (see Chapter 11 on descriptive analysis and Civille and Lyon (1996) for a database of descriptors for many products). There is not, at this point, any internationally standardized odor terminology, in part because of the number of odors that can be found. According to Harper (1972), some 17,000 odorous compounds are known. A trained descriptive panel often can differentiate and name several thousands of odors, and trained flavorists or perfumers can name thousands more. Many terms may be ascribed to a single compound (e.g., thymol = herb-like, green, rubber-like), and a single term may be associated with many compounds (lemon = α-pinene, β-pinene, α-limonene, β-ocimene, citral, citronellal, linalool, α-terpineol, etc.). Examples of this can be found in a number of different publications (e.g., Lota et al., 2002; Vekiari et al., 2002; Smadja et al., 2005).

2.2.3 Consistency and Texture

The third set of attributes to be considered are those perceived by sensors in the mouth other than taste and chemical feelings. Texture also is perceived by the skin and muscles of the body, other than those in the mouth, when evaluating food products (e.g., squeezing fruit or bread) personal care products (e.g., rubbing lotion onto the skin), home care products (e.g., scrubbing a hard surface during cleaning), or other products (e.g., the force needed to tear or cut a paper or textiles).

Viscosity typically refers to the rate of a Newtonian liquid's flow under some force such as gravity or stirring. It can be measured accurately (at a standard temperature) and varies from a low of approximately 1 cP (centipoise) for water or beer to 1000s of cP for thick products such as some sugar syrups, honey, or molasses.

Consistency (of fluids such as purees, sauces, juices, syrups, jellies, and cosmetics), in principle, must be measured by sensory evaluation (Kramer and Twigg, 1973). However, with practice, some standardization is possible with the aid of consistometers (Kramer and Twigg, 1973; Mitchell, 1984) to measure the flow properties.

Texture is complex, as demonstrated by the existence of an entire journal devoted to the subject, the *Journal of Texture Studies*. *Texture* can be defined as the sensory manifestation of the structure or inner makeup of products in terms of their

- Reaction to stress, measured as mechanical properties (such as hardness/firmness, adhesiveness, cohesiveness, gumminess, springiness/resilience, viscosity) by the kinesthetic sense in the muscles of the hand, fingers, tongue, jaw, or lips
- Tactile feel properties, measured as geometrical particles (grainy, gritty, crystalline, flaky) or moisture properties (wetness, oiliness, moistness, dryness) by the tactile nerves in the surface of the skin of the hand, lips, or tongue (Szczesniak, 1963)

Table 2.1 lists general mechanical, geometrical, and moisture properties of foods, skincare products, and fabrics. Note that across such a wide variety of products, the textural properties are all derived from the same general classes of texture terms measured kinesthetically or in terms of tactile qualities. Additional texture terms are listed in Appendixes 12.1, 12.2, and 12.4. A recommended review of texture perception and measurement is that of De Man et al. (1976).

Table 2.1 Components of Texture

Mechanical Properties: Reaction to Stress, Measured Kinesthetically		
Foods	**Skincare**	**Fabrics**
Hardness: Force to Attain a Given Deformation		
Firmness (compression)	Force to compress	Force to compress
Hardness (bite)	Force to spread	Force to stretch
Cohesiveness: Degree to Which Sample Deforms (Rather than Ruptures)		
Cohesive	Cohesive	Stiffness
Chewy	Short	
Fracturable (crispy/crunchy)	Viscosity	
Viscosity		
Adhesiveness: Force Required to Remove Sample from a Given Surface		
Sticky (tooth/palate)	Tacky	Fabric/fabric friction
Toothpack	Drag	Hand friction (drag)
Denseness: Compactness of Cross-Section		
Dense/heavy	Dense/heavy	Fullness/flimsy
Airy/puffy/light	Airy/light	
Springiness: Rate of Return to Original Shape after Some Deformation		
Springy/rubbery	Springy	Resilient (tensile and compression)
		Cushy (compression)

Geometrical Properties: Perception of Particles (Size, Shape, Orientation) Measured by Tactile Means	
Smoothness	Absence of all particles
Gritty	Small, hard, sharp particles
Grainy	Small, round particles
Chalky/powdery	Fine particles (film)
Fibrous	Long, stringy particles (fuzzy fabric)
Lumpy/bumpy	Large, even pieces or protrusions

Moisture Properties: Perception of Water, Oil, Fat, Measured by Tactile Means		
Foods	**Skincare**	**Fabrics**
Moistness: Amount of Wetness/ Oiliness Present, When Not Certain Whether Oil and/or Water Moisture Release: Amount of Wetness/ Oiliness Exuded		
Juicy	Wets down	Moisture release
Oily	Amount of liquid fat	
Greasy	Amount of solid fat	

2.2.4 Flavor

Flavor, as an attribute of foods, beverages, and seasonings, has been defined (Amerine et al., 1965, 549) as the sum of perceptions resulting from stimulation of the sense ends that are grouped together at the entrance of the alimentary and respiratory tracts. However, for purposes of practical sensory analysis, Caul (1957) is followed, and the term is restricted to the impressions perceived via the chemical senses from a product in the mouth. Defined in this manner, flavor includes

- The aromatics, that is, olfactory perceptions caused by volatile substances released from a product in the mouth via the posterior nares
- The tastes, that is, gustatory perceptions (salty, sweet, sour, bitter, umami) caused by soluble substances in the mouth
- The chemical feeling factors that stimulate nerve ends in the soft membranes of the buccal and nasal cavities (astringency, spice heat, cooling, bite, metallic feel, burn)

A large number of individual flavor words are listed in Chapter 11 and in Civille and Lyon (1996).

2.2.5 Noise

The noise produced during the mastication of foods or the handling of fabrics or paper products is a minor, but not negligible, sensory attribute in those products. However, in products such as automobiles, sound systems, and industrial factories, sound can be a primary sensory factor (either positive or negative). It is common to measure the pitch, loudness, and persistence of sounds produced by foods or fabrics. The pitch and loudness of the sound contribute to the overall sensory impression. Differences in pitch of some rupturing foods (crispy, crunchy, brittle) provide sensory input that is used in the assessment of freshness/staleness. Oscilloscopic measurements by Vickers and Bourne (1976) permitted a sharp differentiation between products described as crispy and those described as crunchy. Kinesthetically, these differences correspond to measurable differences in hardness, denseness, and the force of rupture (fracturability) of a product. A crackly or crisp sound on handling can cause a subject to expect stiffness in a fabric. The duration or persistence of sound from a product often suggests other properties, for example, strength (crisp fabric), freshness (crisp apples, potato chips), toughness (squeaky clams), or thickness (plopping liquid). Table 2.2 lists common noise characteristics of foods, skincare products, and fabrics.

In other products such as motorcycles, where the sound is a key consumer attribute, the sound can become almost synonymous with the brand; for example, Harley-Davidson Corp. attempted to trademark the sound of a Harley-Davidson motorcycle. Stereo equipment manufacturers must evaluate the output sound of the systems they create (Smith, 2010), and companies that manufacture so-called noise-cancelling headphones must ensure that ambient noise does not compete with the sounds the listener wants to enjoy. Acoustics is a developing area for sensory scientists.

Table 2.2 Common Noise Characteristics of Foods, Skincare Products, and Fabrics

Noise Properties[a]		
Foods	**Skincare**	**Fabrics**
Crispy	Squeak	Crisp
Crunchy		Crackle
Squeak		Squeak

Pitch: Frequency of sound.
Loudness: Intensity of sound.
Persistence: Endurance of sound over time.
[a] Perceived sounds (pitch, loudness, persistence) and auditory measurement.

2.3 HUMAN SENSES

The five senses are so well covered in textbooks (Piggott, 1988; Kling and Riggs, 1971; Sekuler and Blake, 1990; Geldard, 1972) that a description here is superfluous. Therefore, this discussion will be limited to pointing out some characteristics that are of particular importance in designing and evaluating sensory tests. A clear and brief account of the sensors and neural mechanisms that are used to perceive odor, taste, vision, and hearing, followed by a chapter on the intercorrelation of the senses, is found in *Basic Principles of Sensory Evaluation* (American Society for Testing and Materials [ASTM], 1968). Lawless and Heymann (1998) review what is known about sensory interaction within and between the sensory modalities.

2.3.1 Sense of Vision

Light entering the lens of the eye (see Figure 2.1) is focused on the retina, where the rods and cones convert it to neural impulses that travel to the brain via the optic nerve. Some aspects of color perception that must be considered in sensory testing are that

- Subjects often give consistent responses about an object's color even when filters are used to mask differences (perhaps because the filters mask hues but generally do not mask brightness and chroma). Thus, using red lights for meat may work to mask differences in perceived degree of doneness (i.e., red vs. pink vs. brown), but will not mask differences in the visual perception of dryness, the appearance of fat or muscle fibers, or the outside "char" that is on a grilled product.
- Subjects are influenced by adjoining or background color, and the relative sizes of areas of contrasting color (i.e., a blotchy appearance, as distinct from an even distribution of color) affects perception.
- The gloss and texture of a surface also affect the perception of color.
- Color vision differs among subjects: Degrees of color blindness exist, for example, the inability to distinguish between red and orange or blue and green; and exceptional color sensitivity also exists, allowing certain subjects to discern visual differences that the panel leader cannot see.

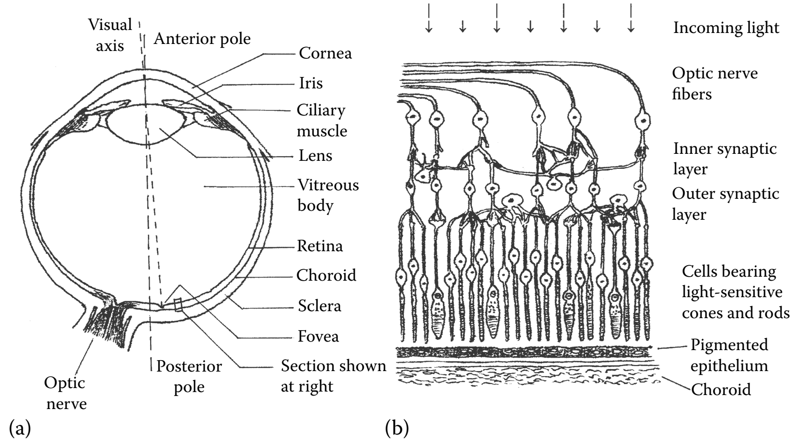

Figure 2.1 The eye, showing the lens, retina, and optic nerve. The entrance of the optic nerve is the blind spot. The fovea is a small region, central to the retina, that is highly sensitive to detail and consists entirely of cones. (Modified from Hochberger, J. E. [1964] *Perception*. Englewood Cliffs, NJ: Prentice-Hall. With permission.)

The chief lesson to be learned from this is that attempts to mask differences in color or appearance are often unsuccessful, and if undetected, they can cause the experimenter to erroneously conclude that a difference in flavor or texture exists, when the difference is actually in a visual appearance characteristic.

2.3.2 Sense of Touch

The group of perceptions generally described as the sense of touch can be divided into *somesthesis* (tactile sense, skinfeel) and *kinesthesis* (deep pressure sense or proprioception), with both sensing variations in physical pressure. Figure 2.2 shows the several types of nerve endings in the skin surface, epidermis, dermis, and subcutaneous tissue. These surface nerve ends are responsible for the somesthetic sensations called touch, pressure, heat, cold, itching, and tickling. Deep pressure, kinesthesis, is felt through nerve fibers in muscles, tendons, and joints, the main purpose of which is to sense the tension and relaxation of muscles. Figure 2.3 shows how the nerve fibers are buried within a tendon. Kinesthetic perceptions corresponding to the mechanical movement of muscles (heaviness, hardness, stickiness, etc.) result from stress exerted by muscles of the hand, jaw, or tongue and the sensation of the resulting strain (compression, shear, rupture) within the sample being handled, masticated, and so on. The surface sensitivity of the lips, tongue, face, and hands is much greater than that of other areas of the body, resulting in the ease of detection of small force differences, particle size differences, and thermal and chemical differences from hand and oral manipulation of products.

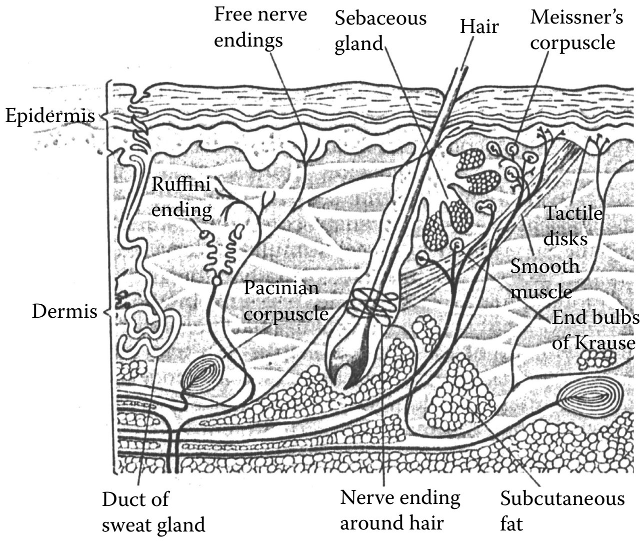

Figure 2.2 Composite diagram of the skin in cross section. Tactile sensations are transmitted from a variety of sites; for example, the free nerve endings and the tactile discs in the epidermis, and, in the dermis, the Meissner corpuscles, end bulbs of Krause, Ruffini endings, and Pacinian corpuscles. (From Gardner, E. [1968] *Fundamentals of Neurology*, 5th ed. Philadelphia: W.B. Saunders.)

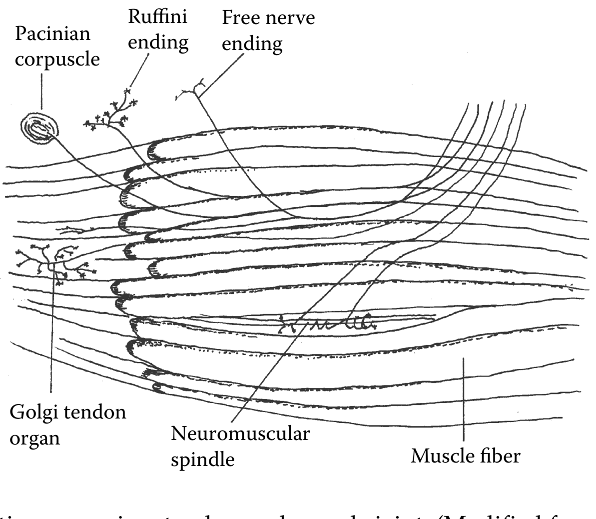

Figure 2.3 Kinesthetic sensors in a tendon and muscle joint. (Modified from Geldard, F.A. [1972]. *The Human Senses*. New York: Wiley. With permission.)

2.3.3 Olfactory Sense

2.3.3.1 General

Airborne odorants are sensed by the olfactory epithelium, which is located in the roof of the nasal cavity (see Figure 2.4). Odorant molecules are sensed by the millions of tiny, hair-like cilia that cover the epithelium and are enervated by more than 1000 different olfactory receptor types (Buck and Axel, 1991). The anatomy of the nose is such that only a small fraction of inspired air reaches the olfactory epithelium via the nasal turbinates or via the back of the mouth on swallowing (Maruniak, 1988). Optimal contact is obtained by moderate inspiration (sniffing) for 1–2 s (Laing, 1983). At the end of 2 s, the receptors have adapted to the new stimulus, and one must allow 5–20 s or longer for them to de-adapt before a new sniff can produce a full-strength sensation. A complication is that the odorant(s) can fill the location where a stimulus is to be tested, thereby reducing the subject's ability to detect a particular odorant or differences among similar odorants. Cases of total odor blindness, *anosmia*, are rare, but specific anosmia, the inability to detect specific odors, is common (Harper, 1972). For this reason, potential panelists should be screened for sensory acuity using odors similar to those to be tested.

Whereas the senses of hearing and sight can accommodate and distinguish stimuli that are 10^4- to 10^5-fold apart, the olfactory sense has trouble accommodating a 10^2-fold difference between the threshold and the concentration that produces saturation of the receptors. On the other hand, whereas the ear and the eye each can sense only one type of signal (namely, oscillations of air pressure and electromagnetic waves of 400–800 nm wavelength), the nose has enormous discriminating power, discriminating many thousands of different odors.

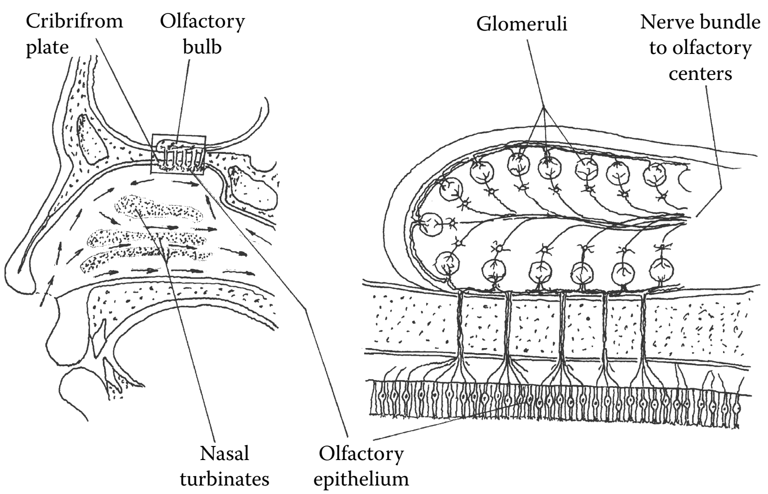

Figure 2.4 Anatomy of the olfactory system. Signals generated by the approximately 1000 types of sensory cells pass through the cribriform plate into the olfactory bulb where they are sorted through the glomeruli before passing on to the higher olfactory centers. (Modified from Axel, R. [1995]. *Sci Am* (October): 154–9.)

The receptors' sensitivity to different chemicals varies over a range of 10^{12} or more (Harper, 1972; Meilgaard, 1975). Typical thresholds (see Table 2.3) vary from 1.3×10^{19} molecules per milliliter air for ethane to 6×10^7 molecules per milliliter for allyl mercaptan, and it is very likely that substances exist or will be discovered that are more potent. Note that pure water and pure air are not in the list because these bathe the sensors and cannot be sensed.

The table illustrates how easily a chemical standard can be misflavored by impurities. For example, an average observer presented with a concentration of 1.5×10^{17} molecules per milliliter of methanol that is 99.99999% pure but contains 0.00001% ionone would perceive a 10 × threshold of methanol but a 100 × threshold odor of ionone. Purification by distillation and charcoal treatment might reduce the level of ionone impurity tenfold, but it would still be at 10 × threshold or as strong as the odor of methanol itself.

Table 2.3 Some Typical Threshold Values in Air

Chemical Substance	Molecules/mL Air
Allyl mercaptan	6×10^{7}
Ionone	1.6×10^{8}
Vanillin	2×10^{9}
sec-Butyl mercaptan	2×10^{8}
Butyric acid	1.4×10^{11}
	6.9×10^{9}
Acetaldehyde	9.6×10^{12}
Camphor	5×10^{12}
	6.4×10^{12}
	4×10^{14}
Trimethylamine	2.2×10^{13}
Phenol	7.7×10^{12}
	2.6×10^{13}
	1×10^{13}
	1.3×10^{15}
Methanol	1.1×10^{16}
	1.9×10^{16}
Ethanol	2.4×10^{15}
	2.3×10^{15}
	1.6×10^{17}
Phenyl ethanol	1.7×10^{17}
Ethane	1.3×10^{19}

Source: From Harper, R. (1972). *Human Senses in Action*, 253. Churchill Livingstone, London. With permission.

Note: The figures quoted should be treated as orders of magnitude only because they may have been derived by different methods.

Gas chromatographic methods are constantly improving and now can detect in the parts per billion ranges. However, there are numerous odor substances, probably thousands, that occur in nature at parts per trillion levels to which the nose is more sensitive than the gas chromatograph. In addition, the complexity of odor mixtures that result in unexpected sensory perceptions is enormous. Researchers are a long way away from being able to predict an odor from gas chromatographic analysis (Chambers and Koppel, 2013).

Although Buck and Axel (1991) identified the genes and the protein receptors that comprise the olfactory epithelium, nothing definite is known about the way the brain handles the incoming information to produce in humans' minds the perception of a given odor quality and the strength of that quality. Much less is known about how the brain handles mixtures of different qualities whose signals arrive simultaneously via the olfactory nerve (Lawless, 1986). For a detailed review of the perception of odorant mixtures, see Doty and Laing (2003).

Moncrieff (1951) lists 14 conditions that any theory of olfaction must fulfill. Odorous molecular compounds on the incoming air, in their many orientations and conformations, are attracted and briefly interact with particular sites in the pattern. An attractive theory is that of Luca Turin (1996).

Buck and Axel (1991) received the 2004 Nobel Prize (Altman, 2004) for their discovery in mammalian olfactory mucosa of a family of approximately 1000 genes, coding for as many different olfactory receptor proteins. This group then found (Axel, 1995) that each olfactory neuron expresses one, and only one, receptor protein. They also found that the neurons that express a given protein all terminate in two and only two of the approximately 2000 glomeruli in the olfactory bulb. It seems to follow that the work of the brain is one of sorting and learning. For example, it may learn that if glomeruli numbers 205, 464, and 1,723 are strongly stimulated, then geraniol's odor has been identified.

Human sensitivity to various odors may be measured by dual flow olfactometry, using *n*-butanol as a standard (Moskowitz et al., 1974). Subjects show varying sensitivity to odors depending on hunger, satiety, mood, concentration, the presence or absence of respiratory infections, and, in women, menstrual cycle and pregnancy (Maruniak, 1988).

Given the complexity of the receptors, the enormous range shown by the thresholds for different compounds, and the sociocultural background of the individual, it is not surprising that different people may receive different perceptions from a given odorant or describe perceptions differently. The largest study ever in this area with consumers was The National Geographic Smell Survey; see Gibbons (1986), Gilbert and Wysocki (1987), Wysocki and Gilbert (1989), and Wysocki, et al. (1991). Recent data using two similarly trained panels from two different cultural and ethnic backgrounds to evaluate a complex food product showed that, generally, differences in the words or names associated with a perception were related to experiences associated with cultural background rather than completely different perceptions of the product (Cherdchu et al., 2013). The lesson to be learned from this is that if the job is to characterize or identify a new odor, one needs a large consumer panel or a group of highly trained experts to describe the perception. A panel of one, regardless of qualifications, can be biased and ultimately misleading.

2.3.3.2 Retronasal Odor

An important part of what is called *flavor-by-mouth* is retronasal odor. When people chew and swallow, some of the volatiles in the mouth pass via the nasopharyngeal passage into the nose where they contact the olfactory epithelium (Figure 2.4). For more detail, see Mozell et al. (1969).

Retronasal perception is often responsible for one's ability to identify an odor or a flavor. As an example, Lawless et al. (2004) showed that the so-called metallic taste of solutions of $FeSO_4$ disappears when both nares are blocked.

2.3.3.3 Odor Memory

A first encounter with an odor often is remembered over a very long time. Factors that affect its acquisition and retention are discussed by Köster et al. (2002). Short-term and long-term odor memory are highly important for an animal's survival in the wild as they are for a human subject's performance on a panel (see Parr, Heatherbell, and White, 2002). A selection of odorants useful in panel selection and training are those of ISO Standards 5496 and 22935, "Initiation and Training of Assessors in the Detection and Recognition of Odours."

A problem in odor memory is that, whereas an odor may be perfectly remembered, people tend to forget its name or to apply to it the name of a similar odor (Jönsson and Olsson, 2003). Similarly, when subjects do recall a name but apply it to a different odor, they may mentally transfer characteristics associated with the name to the new odor (see Köster, et al., 2002).

2.3.4 Chemical/Trigeminal Sense

Chemical irritants such as ammonia, ginger, horseradish, onion, chili peppers, menthol, and so on stimulate the trigeminal nerve ends (see Figure 2.5), causing perceptions of burn, heat, cold, pungency, and so on in the mucosa of the eyes, nose, and mouth. Subjects often have difficulty separating trigeminal sensations from olfactory and/or gustatory ones. Experiments that seek to determine olfactory sensitivity among subjects can be confounded by responses to trigeminal rather than olfactory sensations.

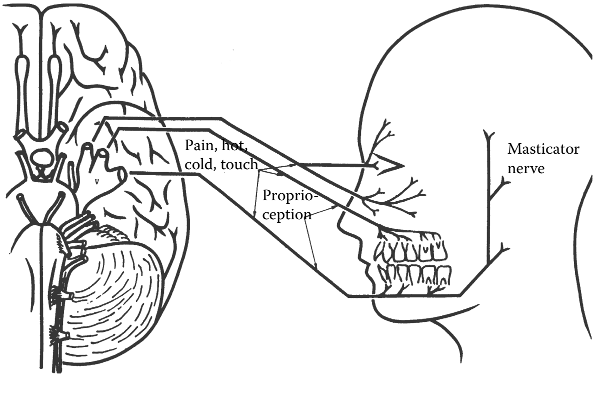

Figure 2.5 Pathway of the trigeminus (V) nerve. (Modified from Netter, F. H. [1973]. *CIBA Collection of Medical Illustrations*, vols. 1 and 3. Summit, NJ: Ciba-Geigy Corporation; readers interested in greater detail are referred to Boudreau, J. C. [1986] *J Sens Stud* 1, 185–202.)

For most compounds, the trigeminal response requires a concentration of the irritant that is higher in orders of magnitude than one that stimulates the olfactory or gustatory receptors. Trigeminal effects assume practical significance (1) when the olfactory or gustatory threshold is high, for example, for short-chain compounds such as formic acid or for persons with partial anosmia or ageusia; and (2) when the trigeminal threshold is low, for example, for capsaicin.

The trigeminal response to mild irritants (such as carbonation, mouth burn caused by high concentrations of sucrose and salt in confections and snacks, the heat of peppers and other spices) may contribute to, rather than distract from, acceptance of a product (Carstens et al., 2002; for review, see Viana, 2011).

2.3.5 Sense of Gustation/Taste

Like olfaction, gustation is a chemical sense (see review by Drewnowski, 2001). It involves the detection of stimuli dissolved in water, oil, or saliva by the taste buds that are primarily located on the surface of the tongue as well as in the mucosa of the palate and areas of the throat. Figure 2.6 shows the taste system in three different perspectives. Compared with olfaction, the contact between a solution and the taste epithelium on the tongue and walls of the mouth is more regular in that every receptor is immersed for at least some seconds. There is no risk of the contact being too brief, but there is ample opportunity for oversaturation. Molecules causing strong bitterness probably bind to the receptor proteins, and some may remain for hours or days (the cells of the olfactory and gustatory epithelium are renewed on average every 6–8 days; Beidler, 1960; Oakley and Riddle, 1992). The prudent taster should take small sips and keep each sip in the mouth for only a couple of seconds, then wait (depending on the perceived strength) for 15–60 s before tasting again. The first and second sips are the most sensitive, and one should train oneself to accomplish in those first sips all the mental comparisons and adjustments required by the task at hand. Where this is not possible, for example, in a lengthy questionnaire with more than eight or ten questions and untrained subjects, the experimenter must be prepared to accept a lower level of discrimination.

The gustatory sensors are bathed in a complex solution, the saliva (which contains water, amino acids, proteins, sugars, organic acids, salts, etc.), and they are fed and maintained by a second solution, the blood (which contains an even more complex mixture of the same substances). Hence, humans' sensitivities to levels (e.g., of salt) that are lower than those in saliva is low and ill defined. Typical thresholds for taste substances are shown in Figure 2.7.

The range between the weakest tastant, sucrose, and the strongest, Strophantin (a bitter alkaloid) is no more than 104, much smaller than the range of 1012 shown by odorants. The figure also shows the range of thresholds for 47 individuals, and it is seen that the most and least sensitive individuals generally differ by a factor of 102. In the case of phenylthiocarbamide (also phenylthiourea), a bimodal distribution is seen (Amerine et al., 1965, 109): The population consists of two groups, one with an average threshold of 0.16 g/100 mL and another with an average threshold of 0.0003 g/100 mL. Vanillin is another substance that appears to show two peaks (Meilgaard, et al., 1982), but the total number of compounds for which bimodal distributions have been reported is small, and

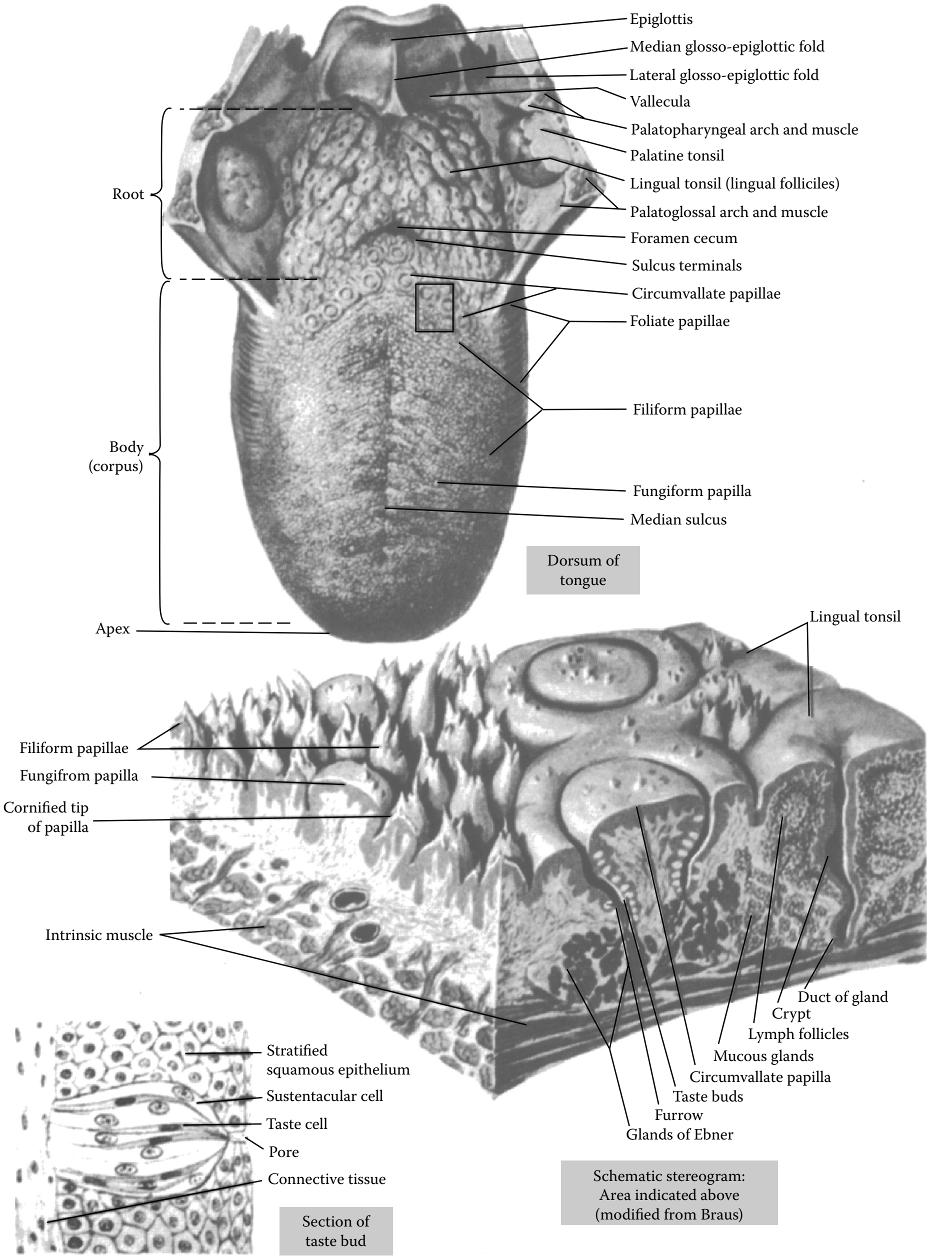

Figure 2.6 Anatomical basis of gustation, showing the tongue, a cross section of a fungiform papilla, and a section thereof showing a taste bud with receptor cells. The latter carry chemosensitive villi that protrude through the taste pore. At the opposite end, their axons continue until they make synaptic contact with cranial nerve VII, the chorda tympani. The surrounding epithelial cells will eventually differentiate into taste receptor cells that renew the current ones as often as once a week.

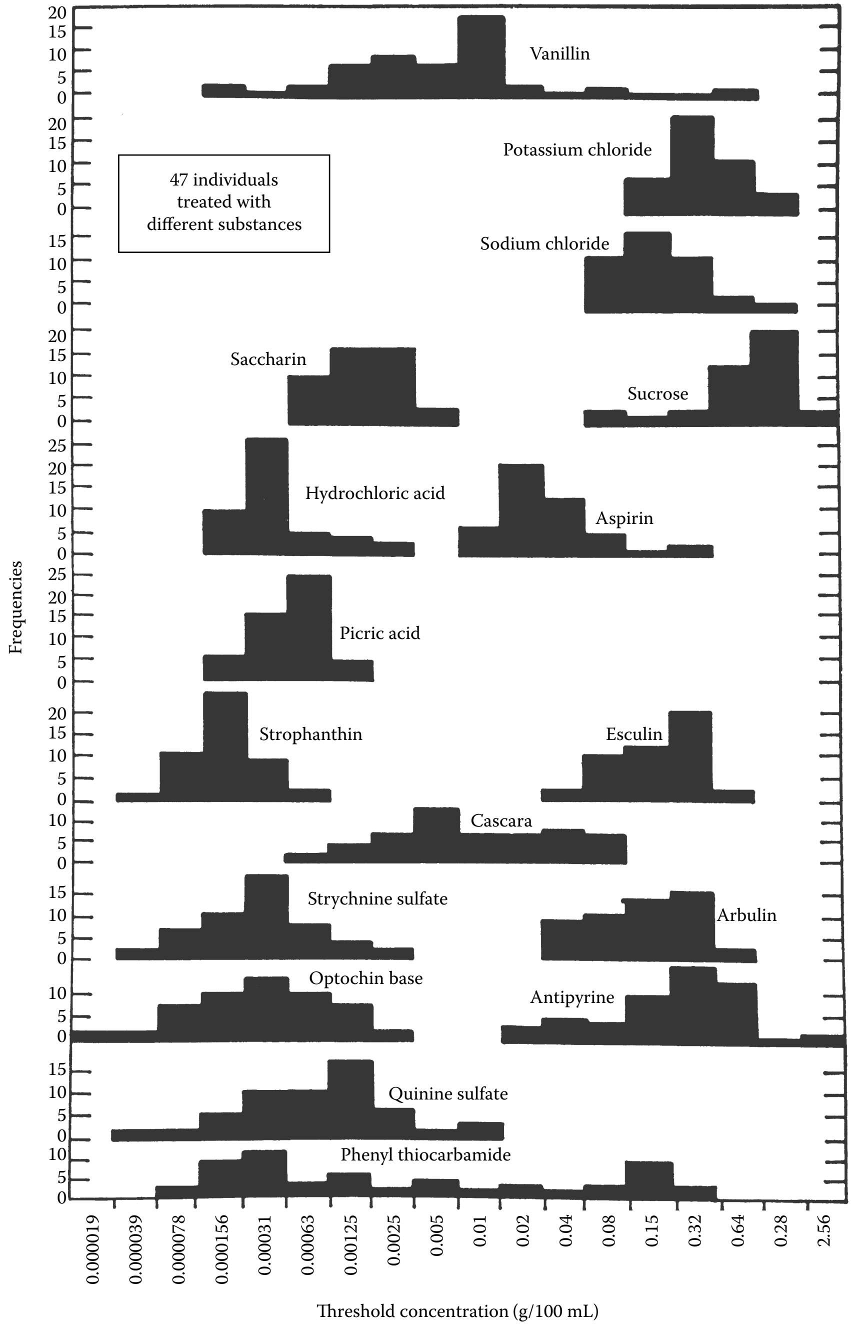

Figure 2.7 Distribution of taste thresholds for 47 individuals (From Amerine, M. A., et al., [1965]. *Principles of Sensory Evaluation of Food*, 109. New York: Academic Press. With permission.)

their role in food preferences or in odor and taste sensitivity is a subject that has not been explored (Amoore, 1977).

Genetic predisposition to perception of certain compounds (e.g., 6-n-propylthiouracil [PROP]) also exists. In the case of PROP, individuals with two recessive alleles are unable to taste bitterness in PROP. Individuals with one or two dominant alleles are PROP tasters, and those with two alleles generally find the bitter taste of PROP extremely high. One cautionary note is that the impact of taster status for one compound has not yet been shown definitively to have anything to do with the taste or odor perception of other compounds. For example, Li and Drewnoski (2000) did not find any association of PROP taster status to the liking of chocolate or sweetened caffeine solutions.

In addition to the concentration of a taste stimulus, other conditions in the mouth that affect taste perception are the temperature, viscosity, rate, duration, and area of application of the stimulus; the chemical state of the saliva; and the presence of other tastants in the solution being tasted. The incidence of ageusia, or the absence of the sense of taste, is rare. However, variability in taste sensitivity, especially for bitterness with various bitter agents, is quite common.

Researchers' understanding of the physiological mechanisms of the principal tastes has been advancing rapidly; for example, sweet (Li et al., 2001; Montmayeur et al., 2001; Nelson et al., 2001); sweet and bitter (Ruiz et al., 2001); sweet and umami (Li et al., 2002; Zhao et al., 2003); sweet, bitter, and umami (Zhang et al., 2003); and sour (Johanningsmeier, et al., 2005).

2.3.6 Sense of Hearing

Figure 2.8 shows a cross section of a human ear. Vibrations in the local medium, usually air, cause the eardrum to vibrate. The vibrations are transmitted via the small bones in the middle ear to create hydraulic motion in the fluid of the inner ear, the cochlea, which is a spiral canal covered in hair cells that, when agitated, send neural impulses to the brain. Students studying crispness and other sound aspects of products should familiarize themselves with the concepts of intensity, measured in decibels; and pitch, determined by the frequency of sound waves. A possible source of variation or error that must be controlled in such studies is the creation and/or propagation of sound inside the cranium but outside the ear; for example, by movement of the jaws or teeth and propagation via the bone structure.

Psychoacoustics is the science of building vibrational models on a sound oscilloscope to represent perceived sound stimuli such as pitch, loudness, sharpness, roughness, and so on. These models work for simple sounds but not for more complex ones. They can be used to answer questions such as "What kind of sound?" and "How loud?" However, they often fail to provide a sound that is appropriate to what the listener expects.

Recently, academics and engineers who are responsible for the sound characteristics of products have realized the need for a common vocabulary to describe sound attributes for complex sounds. This occurs because automobile, airframe, and industrial and consumer products manufacturers are concerned with the sounds that their products produce and how humans respond to those sounds. A summary of sensory methods applied to sound is given by Civille and Seltsam (2003).

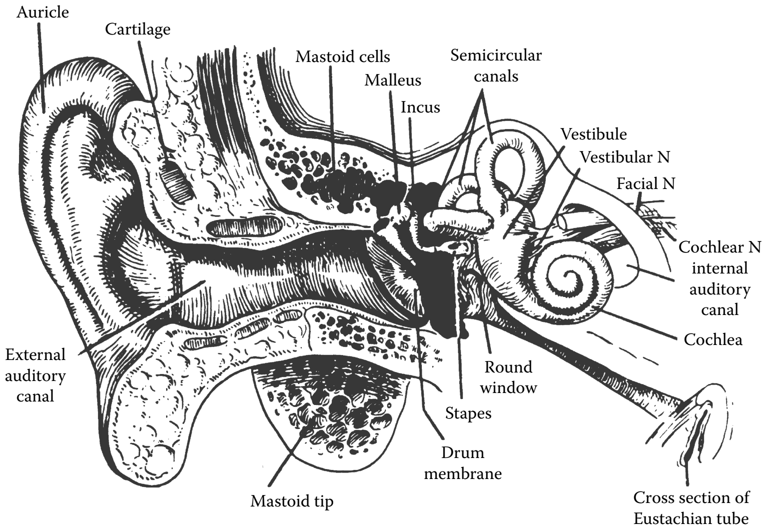

Figure 2.8 A semidiagrammatic drawing of the ear (From Kling, J. W. and L. A. Riggs [1971]. *Woodworth and Schlosberg's Experimental Psychology*, 3rd ed. New York: Holt, Rinehart & Winston. With permission.)

2.4 PERCEPTION AT THRESHOLD AND ABOVE

The reader is warned that a threshold is not a constant for a given substance but rather a constantly changing point on the sensory continuum from nonperceptible to easily perceptible (see Chapter 8). Thresholds change with moods, the time of the biorhythm, with hunger and satiety, and, clearly, from assessor to assessor. Compounds with identical thresholds can show very different rates of increase in intensity with concentration; therefore, the threshold's use as a yardstick of intensity of perception must be approached with considerable caution (Bartoshuk, 1978; Pangborn, 1984). In practical studies involving products that emit mixtures of large numbers of flavor-active substances where the purpose is to detect those compounds that play a role in the flavor of the product, the threshold has some utility, provided the range covered does not extend too far from the threshold; for example, from 0.5 × threshold to 3 × threshold. Above this range, intensity of odor or taste must be measured by scaling (see Chapter 5).

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3

Controls for Test Room, Products, and Panel

3.1 INTRODUCTION

Many variables must be controlled if the results of a sensory test are to measure the true product differences under investigation. It is convenient to group these variables under three major headings:

1. Test controls: the test-room environment, the use of booths or a round table, the lighting, the room air, the preparation area, and the entry and exit areas
2. Product controls: the equipment used, the way samples are screened, prepared, numbered, coded, and served
3. Panel controls: the procedure used by a panelist evaluating the sample in question

3.2 TEST CONTROLS

The physical setting must be designed to minimize the subjects' biases, maximize their sensitivity, and eliminate variables that do not come from the products themselves. Panel tests are costly because of the high cost of panelists' time. A high level of reduction of disturbing factors is easily justified. Drop-offs in panel attendance and panel motivation are universal problems, and management must clearly show the value it places on panel tests by the care and effort expended on the test area. The test area should be centrally located, easy to reach, and free of crowding and confusion, as well as comfortable, quiet, temperature controlled, and above all, free from odors and noise.

3.2.1 Development of Test-Room Design

Since the first edition of this book (1987), test-room design has matured, as reflected in publications by national and international organizations (Eggert and Zook, 1986; European Cooperation for Accreditation of Laboratories, 1995; Chambers and Wolf, 1996;

International Organization for Standardization, 1998). A move toward requiring accreditation of sensory services under ISO 9000 has accelerated a trend toward uniformly high standards, for example, separate air exhausts from each booth.

Early test rooms made allowance for six to ten subjects and consisted of a laboratory bench or conference table on which samples were placed. The need to prevent subjects from interacting, thus introducing bias and distraction, led to the concept of the booth (see Figure 3.1).

In a parallel development, the Arthur D. Little organization (Caul, 1957) argued that panelists should interact and come to a consensus, which required a round table with a "lazy Susan" on which reference materials were placed to standardize terminology and scale values.

Current thinking often combines these two elements into (1) a booth area that is the principal room used for difference tests as well as some descriptive tests, and (2) a round-table area used for training and/or other descriptive tasks (see Figure 3.2). Convenience dictates that a sample-preparation area be located near to, but separate from, the test room. Installations above a certain size also require office area, sample storage area, and data workstation.

3.2.2 Location

The panel test area should be readily accessible to all. A good location is one that most panel members pass on their way to lunch or morning break. If panel members are drawn from the outside, the area should be near the building entrance. Test rooms should be separated by a suitable distance from congested areas because of noise and the opportunity this would provide for unwanted socializing. Test rooms should be away from other noise and from sources of odor such as machine shops, loading docks, production lines, and cafeteria kitchens.

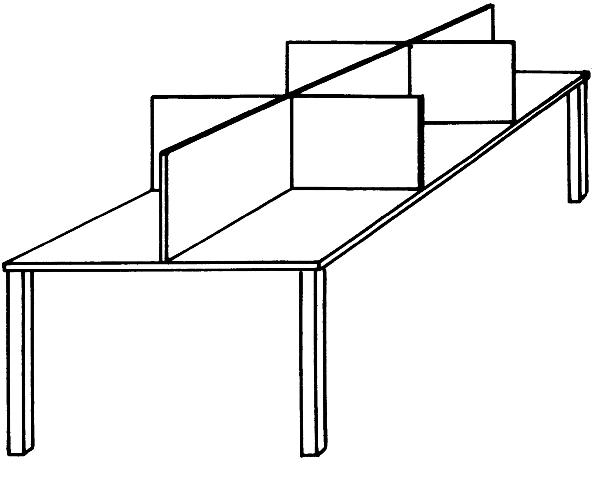

Figure 3.1 Simple booths consisting of a set of dividers placed on a table.

Figure 3.2 Top: circular table with "lazy Susan" used for consensus-type descriptive analysis. (Courtesy of Ross Products Division, Columbus, OH). Bottom: round-table discussion used for descriptive analysis ballot development. (Courtesy of NutraSweet/Kelco Inc., Mt. Pleasant, IL. With permission.)

3.2.3 Test-Room Design

3.2.3.1 Booth

It is customary for one sample-preparation area to serve six to eight booths. The booths may be arranged side by side, in an L shape, or with two sets of three to four booths facing each other across the serving area. The L shape represents the most efficient use of the "work triangle" concept in kitchen design, resulting in a minimum of time and distance covered by technicians in serving samples. One unit of six to eight booths will accommodate a moderate test volume of 300–400 sittings per year of panels up to 18–24 members. For higher volumes of testing and/or larger panels, multiple units served from one or several preparation areas are recommended. Consideration should also be given to placement of the technicians' monitor(s) and central processing unit(s) for any automated data handling system.