Chapter 8

Time–Intensity Methods

Abstract Time–intensity methods represent a special form of intensity scaling that is either repeated at short intervals or continuous. It offers some advantages over a single intensity estimate, giving more detailed information on changes in flavor and texture over time. This chapter reviews the history of these methods, various current techniques, issues, and approaches to data analysis and provides examples of various applications.

In general, humans perceived tastes as changing experiences originating in the mouth, which normally existed for a limited time and then either subsided or transformed into qualitatively different gustatory perceptions. Taste experiences did not begin at the moment of stimulus arrival in the mouth, did not suddenly appear at full intensity, were influenced by the pattern of taste stimulation, and often continued well beyond stimulus removal.

—(Halpern, 1991, p. 95)

Does your chewing gum lose its flavor (on the bedpost overnight)?

—Bloom and Brever, lyrics (recorded by Lonnie Donegan, May 1961, Mills Music, Inc./AA Music)

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8.1 Introduction

Perception of aroma, taste, flavor, and texture in foods is a dynamic not a static phenomenon. In other words, the perceived intensity of the sensory attributes change from moment to moment. The dynamic nature of food sensations arises from processes of chewing, breathing, salivation, tongue movements, and swallowing (Dijksterhuis, 1996). In the texture profile method for instance, different phases of food breakdown were recognized early on as evidenced by the separation of characteristics into first bite, mastication, and residual phases (Brandt et al., 1963). Wine tasters often discuss

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how a wine "opens in the glass," recognizing that the flavor will vary as a function of time after opening the bottle and exposing the wine to air. It is widely believed that the consumer acceptability of different intensive sweeteners depends on the similarity of their time profile to that of sucrose. Intensive sweeteners with too long a duration in the mouth may be less pleasant to consumers. Conversely, a chewing gum with long-lasting flavor or a wine with a "long finish" may be desirable. These examples demonstrate how the time profile of a food or beverage can be an important aspect of its sensory appeal.

The common methods of sensory scaling ask the panelists to rate the perceived intensity of the sensation by giving a single (uni-point) rating. This task requires that the panelists must "time-average" or integrate any changing sensations or to estimate only the peak intensity in order to provide the single intensity value that is required. Such a single value may miss some important information. It is possible, for example, for two products to have the same or similar time-averaged profiles or descriptive specifications, but differ in the order in which different flavors occur or when they reach their peak intensities.

Time–intensity (TI) methods provide panelists with the opportunity to scale their perceived sensations over time. When multiple attributes are tracked, the profile of a complex food flavor or texture may show differences between products that change across time after a product is first tasted, smelled, or felt. For most sensations the perceived intensity increases and eventually decreases but for some, like perceived toughness of meat, the sensations may only decrease as a function of time. For perceived melting, the sensation may only increase until a completely melted state is reached.

When performing a TI study the sensory specialist can obtain a wealth of detailed information such as the following for each sample: the maximum intensity perceived, the time to maximum intensity, the rate and shape of the increase in intensity to the maximum point, the rate and shape of the decrease in intensity to half-maximal intensity and to the extinction point, and the total duration of the sensation. Some of the common time–intensity parameters are illustrated in Fig. 8.1. The additional information derived from time–intensity methods is especially useful when studying sweeteners or products like chewing gums and hand lotions that have a distinctive time profile.

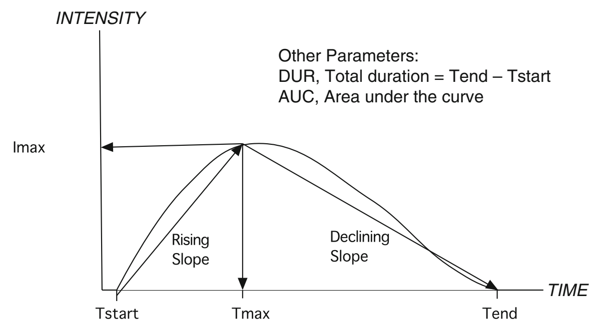

Fig. 8.1 Example of a time–intensity curve and common curve parameters extracted from the record.

The remainder of this chapter will be devoted to an overview of the history and applications of this method, as well as recommended procedures and analyses. For the student who wants only the basic information, the following sections are key: variations on the method (Section 8.3), steps and recommended procedures (Section 8.4), data analysis options (Section 8.5), and conclusions (8.8).

8.2 A Brief History

Holway and Hurvich (1937) published an early report of tracking taste intensity over time. They had their subjects trace a curve to represent the sensations from a drop of either 0.5 or 1.0 M NaCl placed on the anterior tongue surface over 10 s. They noted several general effects that were later confirmed as common trends in other studies. The higher concentration led to a higher peak intensity, but the peak occurred later, in spite of a steeper rising slope. Most importantly they noted that taste intensity was not strictly a function of concentration: "while the concentration originally placed on the tongue is 'fixed,' the intensity varies in a definite manner from moment to moment. Saline intensity depends on time as well as concentration." A review of studies of temporal factors in taste is found in Halpern (1991). A review of TI studies of the 1980s and early 1990s can be found in Cliff and Heymann (1993b).

Sjostrom (1954) and Jellinek (1964) also made early attempts to quantify the temporal response to perceived sensory intensities. These authors asked their panelists to indicate their perceived bitterness of beer at 1 s intervals on a ballot, using a clock to indicate time.

They then constructed TI curves by plotting the x–y coordinates (time on the x-axis and perceived intensity on the y-axis) on graph paper. Once panelists had some experience with the method it was possible to ask them simultaneously to rate the perceived intensities of two different attributes at 1 s intervals. Neilson (1957) in an attempt to make the production of the TI curves easier, asked panelists to indicate perceived bitterness directly on graph paper at 2 s timed intervals. The clock could be distracting to the panelists and thus Meiselman (1968), studying taste adaptation and McNulty and Moskowitz (1974), evaluating oil-in-water emulsions, improved the TI methodology by eliminating the clock. These authors used audible cues to tell the panelists when to enter perceived intensities on a ballot, placing the timekeeping demands on the experimenter rather than the participant.

Larson-Powers and Pangborn (1978), in another attempt to eliminate the distractions of the clock or audible cues, employed a moving strip-chart recorder equipped with a foot pedal to start and stop the movement of the chart. Panelists recorded their responses to the perceived sweetness in beverages and gelatins sweetened with sucrose or synthetic sweeteners, by moving a pen along the cutter bar of the strip-chart recorder. The cutter bar was labeled with an unstructured line scale, from none to extreme. A cardboard cover was placed over the moving chart paper to prevent the panelists from watching the evolving curves and thus preventing them from using any visual cues to bias their responses. A similar setup was independently developed and used at the General Foods Technical Center in 1977 to track sweetness intensity (Lawless and Skinner, 1979). In this apparatus, the actual pen carriage of the chart recorder was grasped by the subject, eliminating the need for them to position a pen; also the moving chart was obscured by a line scale with a pointer attached to the pen carriage. In yet another laboratory at about the same time, Birch and Munton (1981) developed the "SMURF" version of TI scaling (short for "Sensory Measuring Unit for Recording Flux"). In the SMURF apparatus, the subject turned a knob graded from 1 to 10, and this potentiometer fed a variable signal to a strip-chart recorder out of sight of the panelist. The use of strip-chart recorders provided the first continuous TI data-collection methods and freed the panelists from any distractions caused by a clock or auditory signal. However, the methods required a fair degree of mental and physical coordination by the participants. For example, in the Larson-Powers setup, the strip-chart recorder required the panelists to use a foot pedal to run the chart recorder, to place the sample in the mouth, and to move the pen to indicate the perceived intensity. Not all panelists were suitably coordinated and some could not do the evaluation. Although the strip-chart recorder made continuous evaluation of perceived intensities possible, the TI curves had to be digitized manually, which was extremely time consuming.

The opportunity to use computers to time sample an analog voltage signal quite naturally led to online data collection to escape the problem of manual measurement of TI curves. To the best of our knowledge, the first computerized system was developed at the US Army Natick Food Laboratories in 1979 to measure bitter taste adaptation. It employed an electric sensor in the spout just above the subject's tongue in order to determine the actual onset of stimulus arrival. Subthreshold amounts of NaCl were added to the stimulus and thus created a conductance change as the flow changed from the preliminary water rinse to the stimulus interface in the tube. A special circuit was designed to detect the conductance change and to connect the response knob to the visual line scale. Like the SMURF apparatus developed by Birch and Munton, the subject turned a knob controlling a variable resistor. The output of this potentiometer moved a pointer on a line scale for visual feedback while a parallel analog signal was sent to an analog-to-digital converter and then to the computer. The programming was done using FORTRAN subroutines on a popular lab computer of that era. The entire system is shown in Fig. 8.2.

The appearance of desktop computers led to an explosion in the use of TI methodology in the 1980s and 1990s. A number of thesis research projects from U.C. Davis served as useful demonstrations of the method (Cliff, 1987; Dacanay, 1990; Rine, 1987) and the method was championed by Pangborn and coworkers (e.g., Lee and Pangborn, 1986). Several scientists (Barylko-Pikielna et al., 1990; Cliff, 1987; Guinard et al., 1985; Janusz et al., 1991; Lawless, 1980; Lee, 1985; Rine, 1987; Yoshida, 1986) developed computerized TI systems using a variety of hardware and software products. Computerized TI systems are now commercially available as part of data-collection software ensembles, greatly enhancing the ease and availability of TI data collection and data processing.

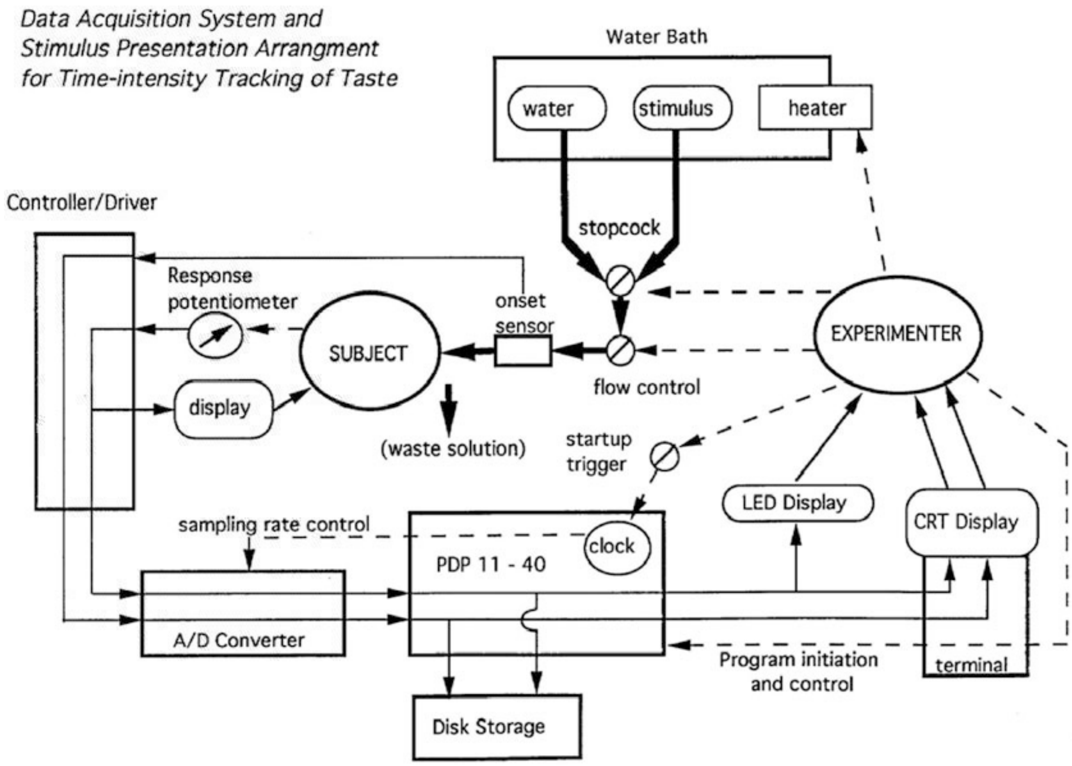

Fig. 8.2 An early computerized system for time–intensity scaling used for tracking bitterness adaptation in a flow system for stimulating the anterior tongue. *Heavy lines* indicate the flow of stimulus solution, *solid lines* the flow of information, and *dashed lines* the experimenter-driven process control. Stimulus arrival at the tongue was monitored by conductivity sensors fitted into the glass tube just above the subject's tongue. The subjects' responses change on a line scale while the experimenter could view the conductivity and response voltage outputs on the computer's display screen, which simultaneously were output to a data file. The system was programmed in FORTRAN subroutines controlling the clock sampling rate and analog-to-digital conversion routine. From Lawless and Clark (1992), reprinted with permission.

However, despite the availability of computerized systems, some research was still conducted using the simple time cueing at discrete intervals (e.g., Lee and Lawless, 1991; Pionnier et al., 2004), and the semi-manual strip-chart recorder method (Ott et al., 1991; Robichaud and Noble, 1990). A discussion of some common applications of TI methods is given in Section 8.6.

8.3 Variations on the Method

8.3.1 Discrete or Discontinuous Sampling

The sensory scientist has several options for collecting time-dependent sensory data. The methods for time-related scaling can be divided into four groups. The oldest approach is simply to ask the panelists to rate the intensity of sensation during different phases of consuming a food. This is particularly applicable to texture which may be evaluated in phases such as initial bite, first chew, mastication, and residual. An example of time division during the texture evaluation of a baked product is shown in Table 8.1.

When using a descriptive panel, it may be useful to have residual flavor or mouthfeel sensations rated at a few small intervals, e.g., every 30 s for 2 min, or immediately after tasting and then again after expectoration. For an example of this approach used with hot pepper "burn" see Stevens and Lawless (1986). Each measurement is then treated like a separate descriptive attribute and analyzed as a separate variable, with little or no attempt to reconstruct a time-connected record like the TI curve shown in Fig. 8.1. For researchers

Table 8.1 Texture attributes at different phases of descriptive analysis

Phase	Attributes	Word anchors
Surface	Roughness	Smooth–rough
	Particles	None–many
	Dryness	Oily–dry
First bite	Fracturability	Crumbly–brittle
	Hardness	Soft–hard
	Particle size	Small–large
First chew	Denseness	Airy–dense
	Uniformity of chew	Even–uneven
Chew down	Moisture absorption	None–much
	Cohesiveness of mass	Loose–cohesive
	Toothpacking	None–much
	Grittiness	None–much
Residual	Oiliness	Dry–oily
	Particles	None–much
	Chalky	Not chalky–very chalky

interested in some simple aspect like "strength of bitter aftertaste" this method may suffice.

Another related approach is to ask for repeated ratings of a single or just a few attributes at repeated smaller time intervals, usually cued by the panel leader or experimenter. These ratings are then connected and graphed on time axis. This is a simple procedure that can be used to track changes in the intensity of a flavor or texture attribute and requires no special equipment other than a stopwatch or other timing device. The panel must be trained to rate their sensations upon the time cue and to move rapidly through the list of attributes. The cue may be given verbally or on a computer screen. It is not known how many attributes can be rated in this way, but with faster time cueing and shorter intervals, obviously fewer attributes may be rated. This method also requires some faith in the assumption that the attributes are being rated close to the actual time when the cue is given. The accuracy with which panelists can do this is unknown, but given that there is a reaction time delay in any perceptual judgment, there must be some inherent error or delay-related variance built into the procedure. An example of the repeated, discrete time interval method with verbal cueing and multiple attributes can be found in studies of sweetener mixtures (e.g., Ayya and Lawless, 1992) and astringency (Lee and Lawless, 1991). The time record is treated as a connected series and time is analyzed as one factor (i.e., one independent variable) in the statistical analysis.

8.3.2 "Continuous" Tracking

A third and widely used method for TI scaling is continuous tracking of flavor or texture using an analog response device such as a lever, a rotating knob, a joystick, or computer mouse. The response device may change a variable resistance and the resulting current is fed through an analog-to-digital conversion. The signal is time sampled at whatever rate is programmed into the recording device. As noted above, continuous records may also be produced by using a chart recorder but digitizing the records may be quite laborious. The advantage of continuous tracking is the detail in the flavor or texture experience that is captured in the record (Lee, 1989; Lee and Pangborn, 1986). It is difficult to capture the rising phase of a flavor with a verbal due or discrete point methods, as the onset of many tastes and odors is quite rapid. The continuous tracking methods are very widely used and are discussed further in Section 8.4. Although the records are continuous, the jagged nature of these records indicates that panelists are not moving the response device in a continuous manner.

Two-dimensional response tasks have been developed so that two attributes can be tracked simultaneously (Duizer et al., 1995). In an experiment on sweetness and mint flavor of chewing gum, it was possible for panelists to track both flavor perceptions simultaneously (Duizer et al., 1996). Panelists were trained to move a mouse diagonally and a visual scale included pointers on both horizontal and vertical scales to represent the intensity of the individual attributes. With a slowly changing product like chewing gum, with a sampling time that is not too frequent (every 9–15 s in this case), the technique would seem to be within the capabilities of human observers to either rapidly shift their attention or to respond to the overall pattern of the combined flavors.

However, as currently used, most TI tracking methods must repeat the evaluation in order to track additional attributes. Ideally, this could lead to a composite profile of all the dynamic flavor and texture attributes in a product and how they changed across time. Such an approach was proposed by DeRovira (1996), who showed how the descriptive analysis spider-web plot of multiple attributes could be extended into the time dimension to produce a set of TI curves and thus to characterize an entire profile.

8.3.3 Temporal Dominance Techniques

A fourth method for gathering time-dependent changes has been to limit the reported profile to a subset of key sensations, called the Temporal Dominance of Sensations (TDS) method (Pineau et al., 2009). This method is still evolving, and descriptions of the procedure and analysis vary somewhat. The basic idea is to present a set of predetermined attributes together on the computer screen for the panelist's choice and scales for rating the intensity of each. The important choice is the selection of the dominant quality and thus the method is related to Halpern's technique for taste quality tracking (Halpern, 1991). Panelists are instructed to attend to and choose only the "dominant" sensation at any one time after tasting the sample and clicking on a start button. "Dominant" has been described as the "most striking perception" (Pineau et al., 2009), "the most intense sensation" (Labbe et al., 2009), "the sensation catching the attention," or "new sensation popping up" at a given time (and not necessarily the most intense) (Pineau et al., 2009) and by no additional definition (Le Reverend et al., 2008). To the extent that one is scoring attributes in order of appearance, the method has some precedent in the original Flavor Profile method.

After sipping or swallowing the sample, the panelist is instructed to click on the start button and immediately choose which attribute on the screen is the dominant one and to rate its intensity, usually on a 10 point or 10 cm line scale. The computer continues to record that intensity until something changes, and a new dominant attribute is selected. In one version of this method, multiple changing attributes can be scored at various time intervals (Le Reverend et al., 2008) "until all sensations have been scored as chronologically perceived." Other publications seem to imply that only one dominant attribute is recorded at any given time (Pineau et al., 2009).

This technique produces a detailed time-by-panelist-by-attribute-by-intensity record. Curves for each attribute can be constructed then by summing across panelists and smoothing the curves. In two other procedures, the data are simplified. Labbe et al. (2009) describe the derivation of an overall TDS score by averaging the intensity multiplied by the duration of each choice, divided by the sum of the durations (i.e., weighted). This produces an integrated value similar to the area-under-the-curve TI scores or those recorded by the SMURF method (intensity multiplied by persistence) in Birch's group (Birch and Munton, 1981). Note that temporal information is used but lost in the scores, i.e., no curves can be constructed from these derived scores. These overall scores were found to correlate well with traditional profiling scores in a series of flavored gels (Labbe et al., 2009). A second derived statistical measure is the proportion of panelists reporting a given attribute as dominant at any given time (Pineau et al., 2009). This ignores the intensity information but produces a simple percentage measure that can be plotted over time to produce a (smoothed) curve for each attribute. "Significance" of an attribute's proportion versus chance is evaluated using a simple one-tailed binomial statistic against a baseline proportion of $1/k$ where k is the number of attributes. The required significance level can be plotted as a horizontal line on the plot of dominance curves to show where attributes are significantly "dominant." Any two products can be compared using the simple binomial test for the difference of two proportions (Pineau et al., 2009). The other information that is available from this procedure is the computation of a difference score for pairs of products, which when plotted over time provides potentially useful information on differences in the dominance of each attribute and how the pattern changes.

The purported advantages of this method are that (1) it is more time and cost efficient than the one-at-a-time TI tracking methods because multiple attributes are rated in each trial, (2) that it is simple and easy to do, requiring little or no training, and (3) that it provides a picture of enhanced differences relative to the TI records. Because panelists are forced to respond to only one attribute at a time, differences in the temporal profile may be accentuated. However, at the time of this publication, no standard procedure seemed to be agreed upon. The technique requires specialized software to collect the information, but at least one of the major sensory software systems has implemented a TDS option. Attributes are assumed to have a score of zero before they become dominant, and some attributes may never be rated. This would seem to necessarily lead to an incomplete record. Different panelists are contributing at different times to different attributes, so statistical methods for comparison of differences between products using the raw data set are difficult. However, products can be statistically compared using the simplified summary scores (summed intensity by duration measures, but losing time information) or by comparison of the proportion of responders (losing intensity information) as in Labbe et al. (2009). Qualitative comparisons can be made from inspecting the curves, such as "this product is initially sweet, then becoming more astringent, compared to product X which is initially sour, then fruity."

Is information provided by TDS and by traditional TI tracking methods different? One study found a strong resemblance of the constructed time curves for both methods, providing virtually redundant information for some attributes (Le Reverend et al., 2008). In another study, correlations with TI parameters were high for intensity maxima versus dominance proportion maxima, as might be expected since a higher number of persons finding an attribute dominant should be related to the mean intensity in TI. Correlations with other time-dependent parameters such as time to $I_{\max}$ ($T_{\max}$) and duration measures were low, due to the different information collected in TDS and the limited attention to one attribute at a time (Pineau et al., 2009).

8.4 Recommended Procedures

8.4.1 Steps in Conducting a Time–intensity Study

The steps in conducting a time–intensity study are similar to those in setting up a descriptive analysis procedure. They are listed in Table 8.2. The first important question is to establish whether TI methods are appropriate to the experimental research objective. Is this a product with just one or a few critical attributes that are likely to vary in some important way in their time course? Is this difference likely to impact consumer acceptance of the product? What are these critical attributes? Next, the product test set should be determined with the research team, and this will influence the experimental design. The TI method itself must be chosen, e.g., discrete point, continuous tracking, or TDS. The sensory specialist should by this time have an idea of what the data set will look like and what parameters can be extracted from the TI records for statistical comparisons such as intensity maxima, time to maxima, areas under the curve, and total duration. Many of the TI curve parameters are often correlated, so there is little need to analyze more than about ten parameters. Practice is almost always essential. You cannot assume that a person sitting down in a test booth will know what to do with the TI system and feel comfortable with the mouse or other response device. A protocol for training TI panelists was outlined by Peyvieux and Dijksterhuis (2001) and this protocol or similar versions have been widely adopted. It is also wise that some kind of panel checking be done to make sure the panelists are giving reliable data (see Bloom et al., 1995; Peyvieux and Dijksterhuis, 2001) and to examine the reasonableness of their data records. At this time the researchers and statistical staff should also decide how to handle missing data or records that may have artifacts or be incomplete. As in any sensory study, extensive planning may save a lot of headaches and problems, and this is especially true for TI methods.

Table 8.2 Steps in conducting a time–intensity study

1. Determine project objectives: Is TI the right method?
2. Determine critical attributes to be rated.
3. Establish products to be used with clients/researchers.
4. Choose system and/or TI method for data collection.
   a. What is the response task?
   b. What visual feedback is provided to the panelists?
5. Establish statistical analysis and experimental design.
   a. What parameters are to be compared?
   b. Are multivariate comparisons needed?
6. Recruit panelists.
7. Conduct training sessions.
8. Check panelist performance.
9. Conduct study.
10. Analyze data and report.

8.4.2 Procedures

If only a few attributes are going to be evaluated, the continuous tracking methods are appropriate and will provide a lot of information. This usually requires the use of computer-assisted data collection. Many, if not all, of the commercial software packages for sensory evaluation data collection have TI modules. The start and stop commands, sampling rate, and inter-trial intervals can usually be specified. The mouse movement will generally produce some visual feedback such as the motion of a cursor or line indicator along a simple line scale. The display often looks like a vertical or horizontal thermometer with the cursor position clearly indicated by bar or line that rises and falls. The computer record can be treated as raw data for averaging across panelists. However, statistical analysis by simple averaging raises a number of issues (discussed in Section 8.5). A simple approach is to pull characteristic curve parameters off each record for purposes of statistical comparisons such as intensity maximum (I_{max}), time to maximum (T_{max}), and area under the curve (AUC). These are sometimes referred to as "scaffolding parameters" as they represent the fundamental structure of the time records. Statistical comparison of these parameters can provide a clear understanding of how different products are perceived with regard to the onset of sensations, time course of rising and falling sensations, total duration, and total sensory impact of that flavor or textural aspect of the products. If a computer-assisted software package is not available or cannot be programmed, the research can always choose to use the cued/discontinuous method (e.g., with a stopwatch and verbal commands). This may be suitable for products in which multiple attributes must be rated in order to get the full picture. However, given the widespread availability of commercial sensory data-collection systems in major food and consumer product companies, it is likely that a sensory professional will have access to a continuous tracking option.

The starting position of the cursor on the visible scale or computer screen should be considered carefully. For most intensity ratings it makes sense to start at the lower end, but for hedonics (like/dislike) the cursor should begin at the neutral point. For meat tenderness or product melting, the track is usually unidirectional, so the cursor should start at "not tender" or "tough" for meat and "not melted" for a product that melts. If the cursor is started at the wrong end of a unidirectional tracking situation, a falsely bi-directional record may be obtained due to the initial movement.

An outline of panel training for TI studies was illustrated in a case study by Peyvieux and Dijksterhuis (2001) and the sensory specialist should consider using this or a similar method to insure good performance of the panelists. These authors had panelists evaluate flavor and texture components of a complex meat product. The prospective panelists were first introduced to the TI method, and then given practice with basic taste solutions over several sessions. The basic tastes were considered simpler than the complex product and more suitable for initial practice. Panelist consistency was checked and a panelist was considered reliable if they could produce two out of three TI records on the same taste stimulus that did not differ more than 40% of the time. A vertical line scale was used and an important specification was when to move the cursor back to zero (when there was no flavor or when the sample was swallowed for the texture attribute of juiciness). Problems were noted with (1) nontraditional curve shapes such as having no return to zero, (2) poor replication by some panelists, (3) unusable curves due to lack of a landmark such as no I_{max}. The authors also conducted a traditional profiling (i.e., descriptive analysis) study before the TI evaluations to make sure the attributes were correctly chosen and understood by the panelists. If TI panelists are already chosen from an existing descriptive panel, this step may not be needed. The authors conducted several statistical analyses to check for consistent use of the attributes, to look for oddities in curve shapes by some panelists, and to examine individual replicates. Improvements in consistency and evidence of learning and practice were noted.

8.4.3 Recommended Analysis

For purposes of comparing products, the simplest approach is to extract the curve parameters such as I_{max}, T_{max}, AUC, and total duration from each record. Some sensory software systems will generate these measures automatically. Then these curve parameters can be treated like any data points in any sensory evaluation and compared statistically. For three or more products, analysis would be by ANOVA and then planned comparisons of means (see Appendix C). Means and significance of differences can be reported in graphs or tables for each curve attribute and product. If a time by intensity curve is desired, the curves can be averaged in the time direction by choosing points at specific time intervals. This averaging method is not without its pitfalls; however, a number of alternative methods are given in the next section. An example of how to produce a simplified averaged curve is given below in the case study of the trapezoidal method (Lallemand et al., 1999).

8.5 Data Analysis Options

8.5.1 General Approaches

Two common statistical approaches have been taken to perform hypothesis testing on TI data. Perhaps the most obvious test is simply to treat the raw data at whatever time intervals were sampled as the input data to analyses of variance (ANOVA) (e.g., Lee and Lawless, 1991). This approach results in a very large ANOVA with at least three factors—time, panelists, and the treatments of interest. Time and panelists effects may not be of primary interest but will always show large F-ratios due to the fact that people differ and the sensations change over time. This is not news. Another common pattern is a time-by-treatment interaction since all curves will tend to converge near baseline at later time intervals. This is also to be expected. Subtle patterns in the data may in fact be captured in other interaction effects or other causes of time-by-treatment interaction. However, it may be difficult to tell whether the interaction is due to the eventual convergence at baseline or to some more interesting effects such as a faster onset time or decay curves that cross over.

As noted above, researchers often select parameters of interest from the TI curve for analysis and comparisons. Landmarks on the curve included the perceived maximum intensity of the sensation, the time needed to reach maximum intensity and duration or time to return to baseline intensity. With computer-assisted data collection many more parameters are easily obtained and parameters such as the area under the curve, the area under the curve before and after perceived maximum intensity, as well as rate from onset to maximum and rate of decay from maximum to endpoint. Additional parameters include plateau time at perceived maximum intensity, lag time prior to start of responses, and the time needed to reach half of the perceived maximum intensity. A list of parameters is shown in Table 8.3.

Thus a second common approach is to extract the curve parameters on each individual record and then perform the ANOVA or other statistical comparison on each of the aspects of the TI curve, as recommended above. For an example, see Gwartney and Heymann (1995) in a study of the temporal perception of menthol. One advantage of this method is that it captures some (but probably not all) of the individual variation in the pattern of the time records. Individual judges' patterns are unique and reproducible within individuals (Dijksterhuis, 1993; McGowan and Lee,

Table 8.3 Parameters extracted from time–intensity curves

Parameter	Other names	Definition
Peak intensity	I_{max}, I_{peak}	Height of highest point on TI record
Total duration	DUR, D_{total}	Time from onset to return to baseline
Area under the curve	AUC, A_{total}	Self-explanatory
Plateau	D_{peak}	Time difference between reaching maximum and beginning descent
Area under plateau	A_{peak}	Self-explanatory
Area under descending phase	P_{total}	Area bounded by onset of decline and reaching baseline
Rising slope	R_i	Rate of increase (linear fit) or slope of line from onset to peak intensity
Declining slope	R_f	Rate of decrease (linear fit) or slope of line from initial declining point to baseline.
Extinction		Time at which curve terminates at baseline
Time to peak	T_{max}, T_{peak}	Time to reach peak intensity
Time to half peak	Half-life	Time to reach half maximum in decay portion

Modified from Lundahl (1992)

Other shape parameters are given in Lundahl (1992), based on a half circle of equivalent area under the curve and dividing the half circle into rising and falling phase segments

2006), an effect that is sometimes described as an individual "signature." Examples of individual signatures are shown in Fig. 8.3. The causes of these individual patterns are unknown but could be attributed to differences in anatomy, differences in physiology such as salivary factors (Fischer et al., 1994), different types of oral manipulation or chewing efficiency (Brown et al., 1994; Zimoch and Gullet, 1997), and individual habits of scaling. Some of this information may be lost when analyzing only the extracted parameters.

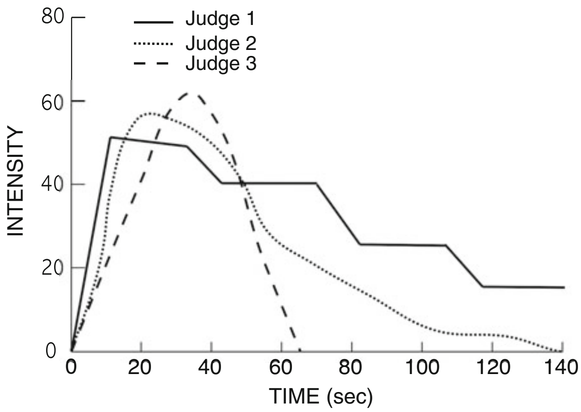

Fig. 8.3 Examples of time–intensity records showing characteristic signatures or shapes. Judge 1 shows a record with multiple plateaus, a common occurrence. Judge 2 shows a smooth and continuous curve. Judge 3 shows a steep rise and fall.

A third approach is to fit some mathematical model or set of equations to each individual record and then use the constants from the model as the data for comparisons of different products (Eilers and Dijksterhuis, 2004; Garrido et al., 2001; Ledauphin et al., 2005, 2006; Wendin et al., 2003). Given the increasing activity and ingenuity in the area of sensometrics, it is likely that such models will continue to be developed. The sensory scientist needs to ask how useful they are in the product testing arena and whether the model fitting is useful in differentiating products. Various approaches to modeling and mathematical description of TI curves are discussed in the next section.

8.5.2 Methods to Construct or Describe Average Curves

The analysis of TI records has produced a sustained interest and response from sensometricians, who have proposed a number of schemes for curve fitting and summarization of individual- and group-averaged TI records. Curve-fitting techniques include fitting by spline methods (Ledauphin et al., 2005, 2006) and various exponential logistic or polynomial equations (Eilers and Dijksterhuis, 2004; Garrido et al., 2001; Wendin et al., 2003). An important question for anyone attempting to model TI behavior by a single equation or set of equations is how well it can take into account the individual "signatures" of panelists (McGowan and Lee, 2006). What appears to be a good approximation to a smooth TI record from one panelist may not be a very good model for the panelist who seems to show a step function with multiple plateaus. It is unknown at this time how many of these schemes have found use in industry or whether they remain a kind of academic exercise. Their penetration into the mainstream of sensory practice may depend on whether they are incorporated into one of the commercial sensory evaluation software data-collection systems.

In the simplest form of averaging, the height of each curve at specific time intervals is used as the raw data. Summary curves are calculated by averaging the intensity values at given times and connecting the mean values. This has the advantage of simplicity in analysis and keeps a fixed-time base as part of the information. However, with this method there may be no detection of an atypical response. As noted above, judges will have characteristic curve shapes that form a consistent style or signature in their response, but that differ in shape from other judges. Some rise and fall sharply. Others form smooth rounded curves while others may show a plateau. Simple averaging may lose some information about these individual trends, especially from outliers or a minority pattern. Furthermore, the average of two different curves may produce a curve shape that does not correspond to either of the input curves. An extreme (and hypothetical) example of this is shown in Fig. 8.4, where the two different peak intensity times lead to an average curve with two maxima (Lallemand et al., 1999). Such a double-peaked curve is not present in the contributing original data.

To avoid these problems, other averaging schemes have been proposed. These approaches may better account for the different curve shapes exhibited by different judges. To avoid irregular curve shapes, it may be necessary or desirable to group judges with similar responses before averaging (McGowan and Lee, 2006). Judges can be subgrouped by "response

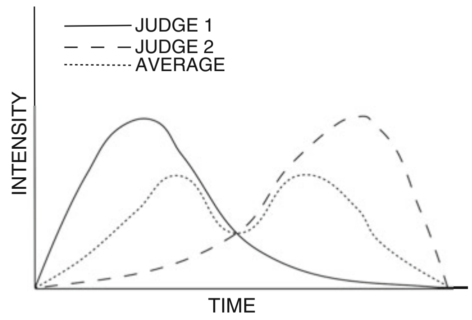

Fig. 8.4 Two curves with different peak times, if averaged, can lead to a double-peaked curve that resembles neither original data record.

style" either by simple visual inspection of the curves or by a clustering analysis or other statistical methods (van Buuren, 1992; Zimoch and Gullet, 1997). Then these subgroups can be analyzed separately. The analysis may proceed using the simple fixed-time averaging of curve heights or one of the other methods described next.

An alternative approach is to average in both the intensity and time directions, by setting each individual's maximum of the mean time to maximum across all curves, and then finding mean times to fixed percentages of maximum in the rising and falling phases of each curve. This procedure was originally published by Overbosch et al. (1986) and subsequent modifications were proposed by Liu and MacFie (1990). The steps in the procedure are shown in Fig. 8.5. Briefly, the method proceeds as follows: In the first step, the geometric mean value for the intensity maximum is found. Individual curves are multiplicatively scaled to have this I_{max} value. In the second step, the geometric mean time to I_{max} is calculated. In the next steps, geometric mean times are calculated for fixed percentage "slices" of each curve, i.e., at fixed percentages of I_{max}. For example, the rising and falling phases are "sliced" at 95% of I_{max} and 90% of I_{max} and the geometric mean time values to reach these heights are found.

This procedure avoids the kind of double-peaked curve that can arise from simple averaging of two distinctly different curve shapes as shown in Fig. 8.4. The method results in several desirable properties that do not necessarily occur with simple averaging at fixed times. First, the I_{max} value from the mean curve is the geometric mean of the I_{max} of the individual curves. Second, the T_{max} value from the mean curve is the geometric mean of the T_{max} of the individual curves. Third, the endpoint is the geometric mean of all endpoint times. Fourth, all judges contribute to all segments of the curve. With simple averaging at fixed times, the tail of the curve may have many judges returned to zero and thus the mean is some small value that is a poor representation of the data at those points. In statistical terms, the distribution of responses at these later time intervals is positively skewed and left-censored (bound by zero). One approach to this problem is to use the simple median as the measure of central tendency (e.g., Lawless and Skinner, 1979). In this case the summary curve goes to zero when over half the judges go to zero. A second approach is to use statistical techniques designed for estimating measures of central tendency and standard deviations from left-censored positively skewed data (Owen and DeRouen, 1980).

Overbosch's method works well if all individual curves are smoothly rising and falling with no plateaus or multiple peaks and valleys, and all data begin and end at zero. In practice, the data are not so regular. Some judges may begin to fall after the first maximum and then rise again to a second peak. Due to various common errors, the data may not start and end at zero, for example, the record may be truncated within the allowable time of sampling. To accommodate these problems, Liu and MacFie (1990) developed a modification of the above procedure. In their procedure, I_{max} and four "time landmarks" were averaged, namely starting time, time to maximum, time at which the curve starts to descend from I_{max} and ending time. The ascending and descending phases of each curve were then divided into about 20 time interval slices. At each time interval, the mean I value is calculated. This method then allows for curves with multiple rising and falling phases and a plateau of maximum intensity that is commonly seen in some judges' records.

8.5.3 Case Study: Simple Geometric Description

A simple and elegant method for comparing curves and extracting parameters by a geometric approximation was described by Lallemand et al. (1999). The authors used the method with a trained texture panel to evaluate different ice cream formulations. The labor-intensive nature of TI studies was illustrated in the fact that

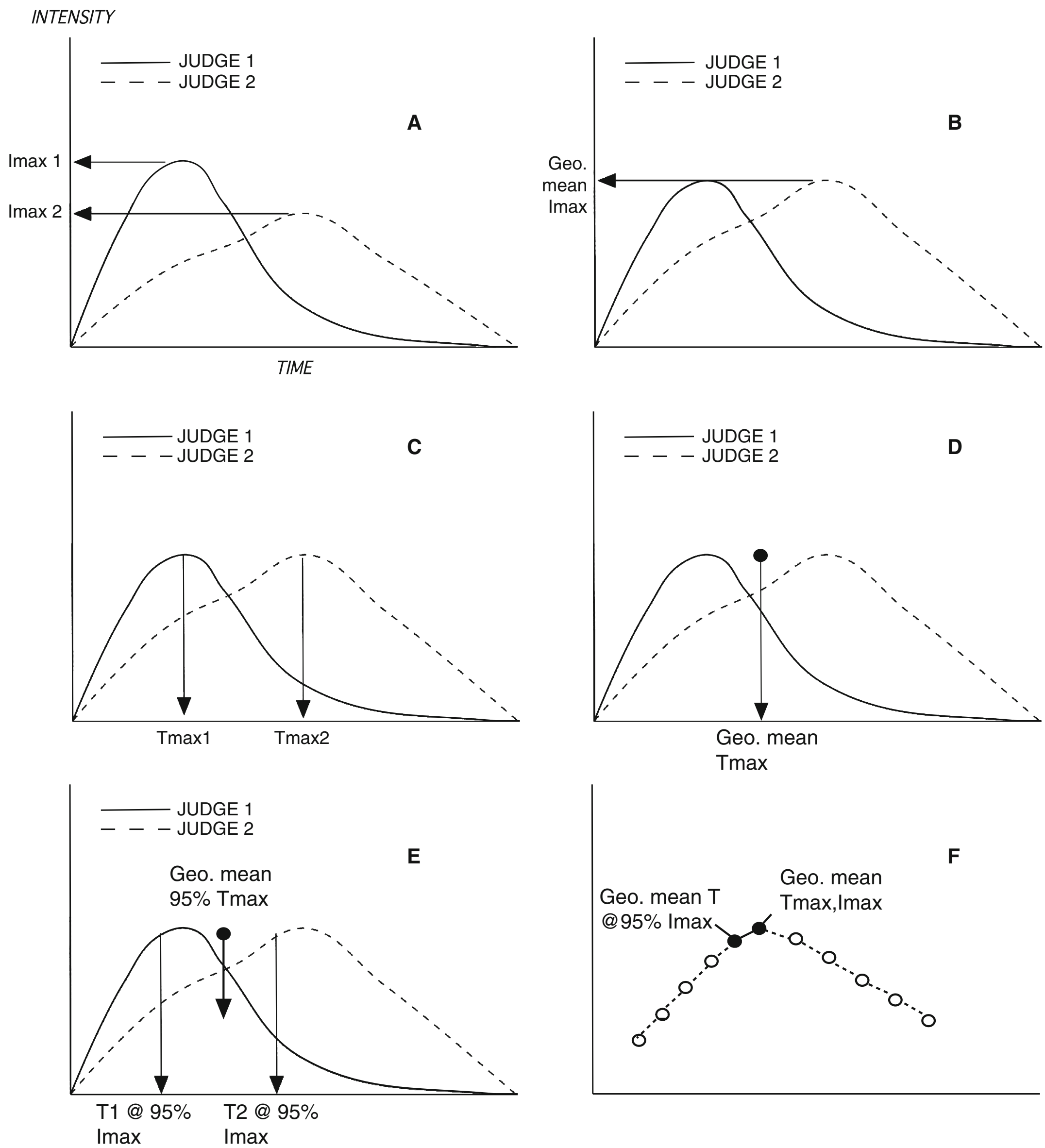

Fig. 8.5 Steps in the data analysis procedure recommended by Overbosch et al. (1986). (**a**) Two hypothetical time–intensity records from two panelists showing different intensity maxima at different times. (**b**) The geometric mean value for the intensity maximum is found. Individual curves may then by multiplicatively scaled to have this I_{max} value. (**c**) The two T_{max} values. (**d**) The geometric mean time to maximum (T_{max}) is calculated. (**e**) Geometric mean times are calculated for fixed percentage "slices" of each curve, i.e., at fixed percentages of I_{max}. The rising phase is "sliced" at 95% of I_{max} and the time values determined. A similar value will be determined at 95% of maximum for the falling phase. (**f**) The geometric mean times at each percent of maximum are plotted to generate the composite curve.

12 products were evaluated on 8 different attributes in triplicate sessions, requiring about 300 TI curves from each panelist! Texture panelists were given over 20 sessions of training, although only a few of the final sessions were specifically devoted to practice with the TI procedure. Obviously, this kind of extensive research program requires a significant time and resource commitment.

Data were collected using a computer-assisted rating program, where mouse movement was linked to the position of a cursor on a 10 cm 10-point scale. The authors noted a number of issues with the data records due to "mouse artifacts" or other problems. These included sudden unintended movement of the mouse leading to false peaks or ratings after the end of the sensation, mouse blockage leading to unusable records, and occasional inaccurate positioning by panelists causing data that did not reflect their actual perceptions. Such ergonomic difficulties are not uncommon in TI studies although they are rarely reported or discussed. Even with this highly trained panel, from 1 to 3% of the records needed to be discarded or manually corrected due to artifacts or inaccuracies. Sensory professionals should not assume that just because they have a computer-assisted TI system, the human factors in mouse and machine interactions will always work smoothly and as planned. Examples of response artifacts are shown in Fig. 8.6.

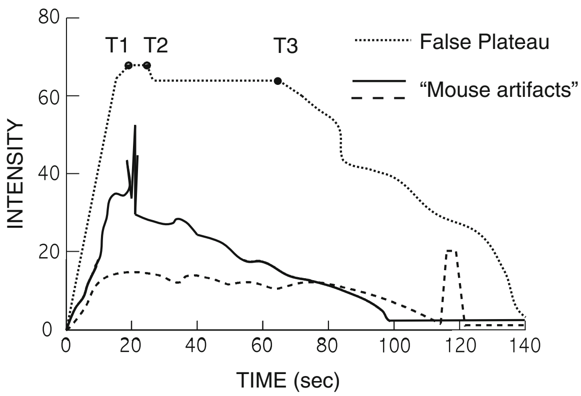

Fig. 8.6 Response artifacts in TI records. The *solid line* shows some perhaps unintended mouse movement (muscle spasm?) near the peak intensity. The *dashed line* shows a bump in the mouse after sensation ceased and returned to zero. The *dotted line* illustrates an issue in determining at what point the intensity plateau has ended. The short segment between *T*1 and *T*2 may have simply been an adjustment of the mouse after the sudden rise, when the panelist felt they overshot the mark. The actual end of the plateau might more reasonably be considered to occur at *T*3. (see Lallemand et al. 1999).

Lallemand and coworkers noted that TI curves often took a shape in which the sensation rose to a plateau near peak intensity for a period during which intensity ratings changed very little and then fell to the baseline. They reasoned that a simple geometric approximation by a trapezoid shape might suffice for extracting curve parameters and finding the area under the curve (not unlike the trapezoidal approximation method used for integration in calculus). In principle, four points could be defined that would describe the curve: the onset time, the time at the intensity maximum or beginning of the plateau, the time at which the plateau ended and the decreasing phase began, and the time at which sensation stopped. These landmarks are those originally proposed by Lui and MacFie (1990). In practice, these points turned out to be more difficult to estimate than expected, so some compromises were made. For example, some records would show a gradually decreasing record during the "plateau" and before the segment with a more rapidly falling slope was evident. How much of a decrease would justify the falling phase or conversely, how little of a decrease would be considered still part of the plateau (see Fig. 8.6)? Also, what should one do if the panelist did not return to zero sensation or unintentionally bumped the mouse after reaching zero? In order to solve these issues, the four points were chosen at somewhat interior sections of the curve, namely the times at 5% of the intensity maximum for the onset and endpoint of the trapezoid, and the times at 90% of the intensity maximum for the beginning and end of the plateau.

This approximation worked reasonably well, and its application to a hypothetical record is shown in Fig. 8.7. Given the almost 3,000 TI curves in this one study, the trapezoid points were not mapped by hand or by eye, but a special program written to extract the points. However, for smaller experiments it should be quite feasible to do this kind of analysis "by hand" on any collection of graphed records. The establishment of the four trapezoid vertices now allows extraction of the six basic TI curve parameters for statistical analysis (5 and 90% of maximum intensity points, the four times at those points), as well as the intensity maximum from the original record, and derived (secondary) parameters such as rising and falling slopes and the total area under the curve. Note that the total area becomes simply the sum of the two triangles and the rectangle described by the plateau. These are shown in the lower section of Fig. 8.7. A composite trapezoid can be drawn from the averaged points.

The utility and validity of the method was illustrated in one sample composite record, showing the fruity flavor intensity from two ice creams differing in fat content. Consistent with what might be expected from the principles of flavor release, the higher fat sample had a slower and more delayed rise to the peak (plateau) but a longer duration. This would be predicted if the higher fat level was better able to sequester

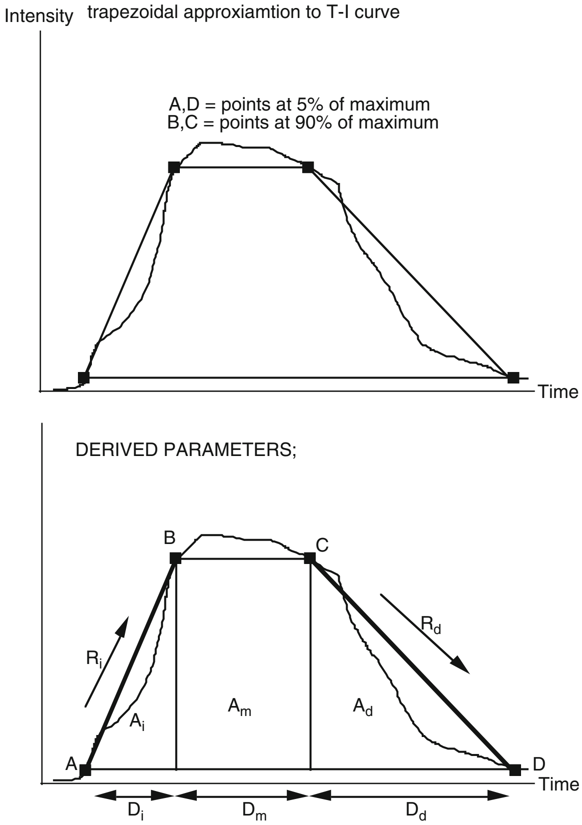

Fig. 8.7 The trapezoidal method of Lallemand et al. (1999) for assessing curve parameters on TI records. The *upper panel* shows the basic scheme in which four points are found when the initial 5% of the intensity maximum (I_{max}) occurs, when 90% of I_{max} is first reached on the ascending segment, when the plateau is finished at 90% of I_{max} on the descending phase and the end-point approximation at 5% of I_{max} on the descending phase. The *lower panel* shows the derived parameters, namely R_i, A_i, and D_i for the rate (slope), area, and duration of the initial rising phase; A_m and D_m for the area and duration of the middle plateau section; and R_d, A_d, and D_d for the rate (slope), area, and duration of the falling phase. A total duration can be found from the sum of D_i, D_m, and D_d. The total area is given by the sum of the A parameters or by the formula for the area of a trapezoid: Total area = $(I_{90}–I_5)\ (2D_m + D_i + D_d)/2$. (Height times the sum of the two parallel segments, then divided by 2).

a lipophilic or nonpolar flavor compound and thus delay the flavor release. They also examined the correlation with a traditional texture descriptive analysis and found very low correlations of individual TI parameters with texture profiling mean scores. This would be expected if the TI parameters were contributing unique information or if the texture profilers were integrating a number of time-dependent events in coming up with their single-point intensity estimates. Consistent with the latter notion, the profiling scores could be better modeled by a combination of several of the TI parameters. The simplicity and validity of this analysis method suggests that it should find wider application in industrial settings.

8.5.4 Analysis by Principal Components

Another analysis uses principal components analysis (PCA, discussed in Chapter 18) (van Buuren, 1992). Briefly, PCA is a statistical method that “bundles” groups of correlated measurements and substitutes a new variable (a factor or principal component) in place of the original variables, thus simplifying the picture. In studying the time–intensity curves for bitterness or different brands of lager beer, van Buuren noticed that individuals once again produced their own characteristic “style” of curve shape. Most people showed a classic TI curve shape, but some subjects were classified as “slow starters,” with a delayed peak and some showed a tendency to persist and not come back down to baseline within the test period. Submission of the data to PCA allowed the extraction of a “principal curve” which captured the majority trend. This showed a peaked TI curve and a gradual return to baseline. The second principal curve captured the shape of the minority trends, with slow onset, a broad peak and slow decline without reaching baseline. The principal curves were thus able to extract judge trends and provide a cleaned-up view of the primary shape of the combined data (Zimoch and Gullet, 1997). Although a PCA program may extract a number of principal components, not all may be practically meaningful (for an example, see Reinbach et al., 2009), and the user should examine each one for the story it tells. Reasonable questions are whether the component reflects something important relative to the simple TI curve parameters, and whether it shows any patterns related to individual differences among panelists.

Dijksterhuis explored the PCA approach in greater detail (Dijksterhuis, 1993; Dijksterhuis and van den Broek, 1995; Dijksterhuis et al., 1994). Dijksterhuis (1993) noted that the PCA method as applied by van Buuren was not discriminating of different bitter stimuli. An alternative approach was “non-centered PCA” in which curve height information was retained during data processing, rather than normalizing curves to a common scale. The non-centered approach works on the raw data matrix. Stimuli or treatments were better distinguished. The first principal curve tends to look like the simple average, while the second principal curve contains rate information such as accelerations or inflection points (Dijksterhuis et al., 1994). This could be potentially useful information in differentiating the subtle patterns of TI curves for different flavors. The PCA approach also involves the possibility of generating weights for different assessors that indicate the degree to which they contribute to the different principal curves. This could be an important tool for differentiating outliers in the data or panelists with highly unusual TI signatures (Peyvieux and Dijksterhuis, 2001).

8.6 Examples and Applications

A growing number of studies have used TI methods for the evaluations of flavor, texture, flavor release, hedonics, and basic studies of the chemical senses. A short review of these studies follows in this section, although the reader is cautioned that the list is not exhaustive. We have cited a few of the older studies to give credit to the pioneers of this field as well as some of the newer applications. The examples are meant to show the range of sensory studies for which TI methods are suitable.

8.6.1 Taste and Flavor Sensation Tracking

A common application of continuous time–intensity scaling is tracking the sensation rise and decay from important flavor ingredients, such as sweeteners (Swartz, 1980). An early study of Jellinek and Pangborn reported that addition of salt to sucrose extended the time–intensity curve and made the taste "more rounded" in their words (Jellinek, 1964). One of the salient characteristics of many intensive or non-carbohydrate sweeteners is their lingering taste that is different from that of sucrose. Time–intensity tracking of sweet tastes was an active area of study (Dubois and Lee, 1983; Larson-Powers and Pangborn, 1978; Lawless and Skinner, 1979; Yoshida, 1986) and remains of great interest to the sweetener industry. Another basic taste that has often been scaled using time–intensity methods is bitterness (Dijksterhuis, 1993; Dijksterhuis and van den Broek, 1995; Leach and Noble, 1986; Pangborn et al., 1983). Beer flavor and bitterness were two of the earliest attributes studied by time–intensity methods (Jellinek, 1964; Pangborn et al., 1983; Sjostrom, 1954; van Buuren, 1992). Robichaud and Noble (1990) studied the bitterness and astringency of common phenolics present in wine and found similar results using traditional scaling and the maximum intensity observed in time–intensity scaling.

Taste properties have been studied in foods and model systems and how they change with other food ingredients and/or flavors present. Sweetness and other flavors may also change in their temporal properties with changes in food formulation, such as changes in viscosity caused by addition of thickening agents or changes due to addition of fat substitutes (Lawless et al., 1996; Pangborn and Koyasako, 1981). In breads, Barylko-Pikielna et al. (1990) measured saltiness, sourness, and overall flavor. TI parameters such as maximum intensity, total duration, and area under the TI curve increased monotonically with salt added to wheat breads. Lynch et al. (1993) found evidence for suppression of taste in gelatin samples when the mouth was precoated with various oils. For some tastes, especially bitter, suppression was evident both in decreased peak intensity and shorter overall duration. Recently, several sensory scientists have applied TI studies to examine flavor intensity in different media and via different routes of olfactory perception. Shamil et al. (1992) showed that lowering the fat content of cheeses and salad dressings caused increases in persistence time and alters the rate of flavor release. Kuo et al. (1993) examined differences in citral intensity comparing orthonasal and retronasal conditions in model systems of citral and vanillin with different tastants or xanthan gum added. In time–intensity study of flavors in different dispersion media, Rosin and Tuorila (1992) found pepper to be more clearly perceived in beef broth than potato, while garlic was equally potent in either medium. Another active area for time-related judgments has been in the study of flavor interactions. Noble and colleagues have used time–intensity measurements to study the interactions of sweetness, sourness, and fruitiness sensations in beverages and simple model systems (Bonnans and Noble, 1993;

Cliff and Noble, 1990; Matysiak and Noble, 1991). Using these techniques, enhancement of sweetness by fruity volatiles has been observed, and differences in the interactions were seen for different sweetening agents.

8.6.2 Trigeminal and Chemical/Tactile Sensations

Reactions to other chemical stimuli affecting irritation or tactile effects in the mouth have been a fertile area for time-related sensory measurements. Compounds such as menthol produce extended flavor sensations and the time course is concentration dependent (Dacanay, 1990; Gwartney and Heymann, 1995). A large number of studies of the burning sensation from hot pepper compounds have used time–intensity scaling, using repeated ratings at discrete time intervals as well as continuous tracking (Cliff and Heymann, 1993a; Green, 1989; Green and Lawless, 1991; Lawless and Stevens, 1988; Stevens and Lawless, 1986). Given the slow onset and extended time course of the sensations induced by even a single sample of a food containing hot pepper, this is a highly appropriate application for time-related judgments. The repeated ingestion paradigm has also been used to study the short- and long-term desensitization to irritants such as capsaicin and zingerone (Prescott and Stevenson, 1996). The temporal profile of different irritative spice compounds is an important point of qualitative differentiation (Cliff and Heymann, 1992). Reinbach and colleagues used TI tracking to study the oral heat from capsaicin in various meat products (Reinbach et al., 2007, 2009) as well as the interactions of oral burn with temperature (see also Baron and Penfield, 1996). When examining the decay curves following different pepper compounds, different time courses can be fit by different decay constants in a simple exponential curve of the form

$$R = R_o e^{-kt} \tag{8.1}$$

or

$$\ln R = \ln R_o - kt \tag{8.2}$$

where R_o is the peak intensity and t is time, k is the value determining how rapid the sensation falls off from peak during the decay portion of the time curve (Lawless, 1984).

Another chemically induced tactile or feeling factor in the mouth that has been studied by TI methods is astringency. Continuous tracking has been applied to the astringency sensation over repeated ingestions (Guinard et al., 1986). Continuous tracking can provide a clear record of how sensations change during multiple ingestions, and how flavors may build as subsequent sips or tastings add greater sensations on an existing background. An example of this is shown in Fig. 8.8 where the saw-tooth curve shows an increase and builds astringency over repeated ingestions (Guinard et al., 1986). Astringency has also been studied using repeated discrete-point scaling. For example, Lawless and coworkers were able to show differences in the time profiles of some sensory sub-qualities related to astringency, namely dryness, roughness in the mouth, and puckery tightening sensations (Lawless et al., 1994; Lee and Lawless, 1991) depending on the astringent materials being evaluated.

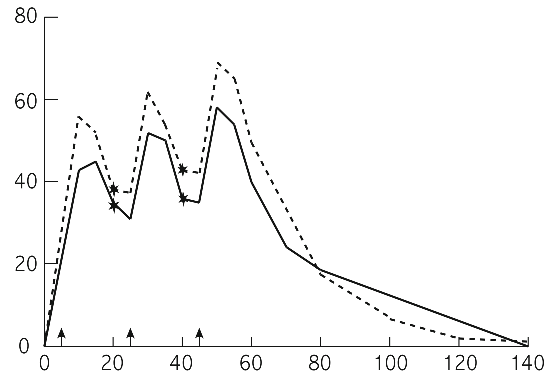

Fig. 8.8 Continuous tracking record with multiple ingestions producing a "sawtooth" curve record. The *abscissa* shows the time axis in seconds and the ordinate the mean astringent intensity from 24 judges. The *dashed curve* is from a 15 ml sample of a base wine with 500 gm/l added tannin and the *solid curve* from the base wine with no added tannin. Sample intake and expectoration are indicated by *stars* and *arrows*, respectively. From Guinard et al. (1986), reprinted with permission of the American Society of Enology and Viticulture.

8.6.3 Taste and Odor Adaptation

The measurement of a flavor sensation by tracking over time has a close parallel in studies of taste and odor adaptation (Cain, 1974; Lawless and Skinner, 1979; O'Mahony and Wong, 1989). Adaptation may be defined as the decrease in responsiveness of a sensory system to conditions of constant stimulation providing a changing "zero point" (O'Mahony, 1986). Adaptation studies have sometimes used discrete, single bursts of stimulation (e.g., Meiselman and Halpern, 1973). An early study of adaptation used a flowing system through the subject's entire mouth using pipes inserted through a dental impression material that was held in the teeth (Abrahams et al., 1937). Disappearance of salt taste was achieved in under 30 s for a 5% salt solution, although higher concentrations induced painful sensations over time that were confusing to the subjects and sometimes masked the taste sensation. By flowing a continuous stream over a section of the subject's tongue or stabilizing the stimulus with wet filter paper, taste often disappears in under a few minutes (Gent, 1979; Gent and McBurney, 1978; Kroeze, 1979; McBurney, 1966). Concentrations above the adapting level are perceived as having the characteristic taste of that substance, e.g., salty for NaCl. Concentrations below that level, to which pure water is the limiting case, take on other tastes so that water after NaCl, for example, is sour–bitter (McBurney, and Shick, 1971). Under other conditions adaptation may be incomplete (Dubose et al., 1977; Lawless and Skinner, 1979; Meiselman and Dubose, 1976). Pulsed flow or intermittent stimulation causes adaptation to be much less complete or absent entirely (Meiselman and Halpern, 1973).

8.6.4 Texture and Phase Change

Tactile features of foods and consumer products have been evaluated using time-related measurements. Phase change is an important feature of many products that undergo melting when eaten. These include both frozen products like ice cream and other dairy desserts and fatty products with melting points near body temperature such as chocolate. Using the chart-recording method for time–intensity tracking, Moore and Shoemaker (1981) evaluated the degree of coldness, iciness, and sensory viscosity of ice cream with different degrees of added carboxymethyl cellulose. The added carbohydrate shifted the time for peak intensity of iciness and extended the sensations of coldness on the tongue. Moore and Shoemaker also studied melting behavior. Melting is an example of a TI curve that does not reach a maximum and then decline, since items placed in the mouth do not re-solidify after melting. In other words, it is unidirectional, from not melted to completely melted. Melting rates have also been studied in table spreads of varying fat composition, with similar unidirectional time curves (Tuorila and Vainio, 1993; see also Lawless et al., 1996).

Other reports have been published applying time–intensity methods to texture evaluation. Larson-Powers and Pangborn (1978) used the strip-chart method to evaluate a number of taste properties of gelatins sweetened with sugar or intensive sweeteners and also evaluated hardness. The hardness curves showed the one-directional decay as expected. Rine (1987) used time–intensity techniques to study the textural properties of peanut butter. Pangborn and Koyasako (1981) were able to track differences in perceived viscosity of chocolate pudding products that differed in their thickening agents. Meat texture has been evaluated during chewing, and tenderness is usually an example of a unidirectional TI curve (Duizer et al., 1995, but see also Zimoch and Gullett (1997) which is bi-directional). Juiciness is another meat texture variable that is well suited to TI evaluation (Peyvieux and Dijksterhuis, 2001; Zimoch and Gullett, 1997). In one early application of TI methods to meat texture, Butler et al. (1996) noted the tendency toward individual "signatures" in the TI records, now a common finding (Zimoch and Gullett, 1997). Jellinek (1985, p. 152) gave an interesting example of how texture may be judged by auditory cures for crispness, and showed time–intensity records of two product differing in both initial crispness and duration. One product made louder sounds initially, but dropped off a steeper rate than another during chewing. Jellinek pointed out that the maintenance of crispness during chewing could be important. Time–intensity methods can thus provide potentially important sensory information about the rate of destruction of a product and texture change during deformation.

8.6.5 Flavor Release

A potentially fertile area for the application of time-related sensory measurements is in flavor release from foods during eating. Not only are texture changes obvious during chewing but also a number of factors operate to change the chemical nature of the matrix within which food flavors exist once the food enters the mouth. The degree to which the individual flavor compounds are held in the matrix as opposed to being released into the mouth space and into the breath and nose of the judge will depend on their relative solubility and binding to the matrix of the food bolus and saliva (McNulty, 1987; Overbosch, 1987). Saliva is a complex mixture of water, salts, proteins, and glycoproteins. It has pH buffering capacity and active enzymes. The flavor volatilization changes as a function of mixing with saliva, pH change, enzymatic processes such as starch breakdown by salivary amylase, warming, mechanical destruction of the food matrix, and changes in ionic strength (Ebeler et al., 1988; Haring, 1990; Roberts and Acree, 1996). Temperature may not only affect the partial vapor pressure of a flavor above the liquid phase but also the degree of association of flavor compounds to proteins and other components of the food matrix (O'Keefe et al., 1991). The flavor balance, interactions with other tastes, and the time properties of release may all be different as a function of sniffing (the orthonasal route to the olfactory receptors) as opposed to sipping (the retronasal route) (Kuo et al., 1993).

A number of devices have been developed to study how volatile flavors are released from food in simulated conditions of oral breakdown (Roberts and Acree, 1996). These usually involve some degree of mechanical agitation or stirring, warming, and dilution in some medium that is designed to reflect the chemical composition of saliva to some degree. Some research has focused on chemical sampling of this altered "headspace," i.e., the vapor phase above the simulated oral mixture (Lee, 1986; Roberts et al., 1996). de Roos (1990) examined flavor release in chewing gum, a matrix from which different flavor compounds are released at different rates, changing the flavor character and detracting from consumer appeal. Large individual differences were observed for common flavors such as vanillin. de Roos was further able to divide his groups into efficient, highly efficient, and inefficient chewers, who differed in their degree and rate of flavor release. This serves to remind us that not everyone masticates in the same way and that mechanical breakdown factors will be different among individuals. Mastication and salivation variables were related to inter-individual differences in flavor release in model cheese systems (Pionnier et al., 2004) using a discrete point TI method.

8.6.6 Temporal Aspects of Hedonics

Since the pleasantness or appeal of a sensory characteristic is largely dependent on its intensity level, it is not surprising that one's hedonic reaction to a product might shift over time as the strength of a flavor waxes and wanes. Time-related shifts in food likes and dislikes are well known. In the phenomenon known as alliesthesia, our liking for a food depends a lot on whether we are hungry or replete (Cabanac, 1971). The delightful lobster dinner we enjoyed last night may not look quite so appealing as leftovers at lunchtime the next day. Wine tasters may speak of a wine that is "closed in the glass, open on the palate, and having a long finish." Accompanying such a description is the implicit message that this particular wine got better over the course of the sensory experience. Given the shorter time span of flavor and texture sensations in the mouth, we can ask whether there are shifts in liking and disliking. This has been measured in several studies. Taylor and Pangborn (1990) examined liking for chocolate milk with varying degrees of milk fat. Different individual trends were observed in liking for different concentrations, and this affected the degree of liking expressed over time. Another example of hedonic TI scaling was in a study of the liking/disliking for the burning oral sensation from chili (hot) pepper (Rozin et al., 1982). They found different patterns of temporal shifting in liking as the burn rose and declined. Some subjects liked the burn at all time intervals, some disliked the burn at all time intervals, and some shifted across neutrality as strong burns became more tolerable. This method was revisited by Veldhuizen et al. (2006) who used a simple bipolar line scale for pleasantness and had subjects evaluated both intensity and hedonic reactions to a citrus beverage flowed over the tongue from a computer-controlled delivery system (see Fig. 8.2 for an early example of this kind of device). Note that with a bipolar hedonic scale, the mouse and cursor positions must begin at the center of the scale and not the lower end as with intensity scaling. The authors found a delayed pleasantness response compared to the intensity tracking, a similar time to maximum, but an unexpectedly quicker offset of response for pleasantness tracking. Some panelists produced a double-peaked pleasantness response, as the sensation could rise in pleasantness, but then become too intense, but become more pleasant again as adaptation set in and the perceived strength decreased.

8.7 Issues

Sensory scientists who wish to use time–intensity methods for any particular study need to weigh the potential for obtaining actionable information against the cost and time involved in collecting these data. Some orientation or training is required (Peyvieux and Dijksterhuis, 2001) and in some published studies, the training and practice is quite extensive. For example, Zimoch and Gullet (1997) trained their meat texture panel for 12 h. Panelists must be trained to use the response device and sufficiently practiced to feel comfortable with the requirements of the task in terms of maintaining focused attention to momentary sensation changes. With the use of online data collection the tabulation and processing of information is generally not very labor intensive; but without computer-assisted collection the time involved can be enormous. Even with computerized systems, the data collection is not foolproof. Responses may be truncated or fail to start at zero in some records (Liu and MacFie, 1990; McGowan and Lee, 2006) making automatic averaging of records infeasible. In one study of melting behavior (Lawless et al., 1996), some subjects mistakenly returned the indicating cursor to zero as soon as the product was completely melted, instead of leaving the cursor on maximum, producing truncated records. Such unexpected events remind us to never assume that panelists are doing what you think they should be doing.

A fundamental issue is information gain. In the case where changes in duration are observed at equal maximum intensities, it can be argued that the traditional scaling might have missed important sensory differences. For example, TI can capture information such as when the TI curves cross over, e.g., the interesting case when a product with a lower peak intensity has a longer duration (e.g., Lallemand et al., 1999; Lawless et al., 1996). However, this pattern is not often seen. Usually products with stronger peak height have longer durations. In general there is a lot of redundant information in TI parameters. Lundahl (1992) studied the correlation of 15 TI parameters associated with TI curves' shapes, sizes, and rates of change. Curve size parameters were highly correlated and usually loaded on the first principal component of a PCA, capturing most of the variance (see also Cliff and Noble, 1990). Curve size parameters, including peak height, were correlated with simple category ratings of the same beverages. So an open question for the sensory scientist is whether there is any unique information in the TI parameters extracted from the records and whether there is information gain over what would be provided by more simple direct scaling using a single intensity rating.

A potential problem in time–intensity methods is that factors affecting response behavior are not well understood. In TI measurements, there are dynamic physical processes (chewing, salivary dilution) leading to changes in the stimulus and resulting sensations (Fischer et al., 1994). A second group of processes concerns how the participant translates the conscious experience into an overt response, including a decision mechanism and motoric activation (Dijksterhuis, 1996). The notion that TI methods provide a direct link from the tongue of the subject to the hand moving the mouse is a fantasy. Even in continuous tracking, there must be some decision process involved. There is no information as to how often a panelist in the continuous procedure reflects upon the sensation and decides to change the position of the response device. Decisions are probably not continuous even though some records from some subjects may look like smooth curves.

An indication that response tendencies are important is when the conditions of stimulation are held constant, but the response task changes. For example, using the graphic chart-recorder method, Lawless and Skinner (1979) found median durations for sucrose intensity that were 15–35% shorter than the same stimuli rated using repeated category ratings. Why would the different rating methods produce apparently different durations? Very different patterns may be observed when taste quality and intensity are tracked. Halpern (1991) found that tracked taste quality of 2 mM sodium saccharin had a delayed onset (by 400 ms) compared with tracked intensity. This might be understandable from the point of requiring a more complex decision process in the case of tracking intensity. However, it still alerts us to the fact that the behavior probably trails the actual experience by some unknown amount. What is more surprising in Halpern's data is that tracked quality also stopped well before tracked intensity (by

600 ms). Can it be possible that subjects are still experiencing a taste of some definable intensity and yet the quality has disappeared? Or is there another response generation process at work in this task?

A third area where potential response biases can operate is in contextual effects. Clark and Lawless (1994) showed that common contextual affects like successive contrast also operated with TI methods, as they do with other scaling tasks. Also, some ratings could be enhanced when a limited number of scales were used by subjects. As observed in single-point scaling, enhancement of sweetness by fruity flavors tends to occur when only sweetness is rated. When the fruity flavor is also rated, the sweetness enhancement often disappears (Frank et al., 1989), an effect sometimes referred to as halo dumping or simply "dumping." Using the discrete-point version of TI scaling, so that multiple attributes could be rated, Clark and Lawless showed a similar effect. This is potentially troublesome for the continuous tracking methods, since they often limit subjects to responding to only one attribute at a time. This may explain in part why sweetness enhancement by flavors can occur so readily in TI studies (e.g., Matysiak and Noble, 1991).

A final concern is the question of whether the bounded response scales often used in TI measurement produces any compression of the differences among products. In analog tracking tasks, there is a limit as to how far the joystick, mouse, lever, dial, or other response device can be moved. With some practice, judges learn not to bump into the top. Yet the very nature of the tracking response encourages judges to sweep a wide range of the response scale. If this were done on every trial, it would tend to attenuate the differences in maximum tracked intensity between products. As an example, Overbosch et al. (1986, see Fig. 2) showed curves for pentanone where doubling the concentration changed peak heights by only about 8%. A similar sort of compression is visible in Lawless and Skinner's (1979) data for sucrose, compared to the psychophysical data in the literature.

8.8 Conclusions

In most cases TI parameters show similar statistical differentiation as compared to traditional scales, but this is not universally the case (e.g., Moore and Shoemaker, 1981).

Many sensory evaluation researchers have supported increased application of time–intensity measurements for characterization of flavor and texture sensations. In particular, the method was championed by Lee and Pangborn, who argued that the methods provide detailed information not available from single estimates of sensation intensity (Lee, 1989; Lee and Pangborn, 1986). TI methods can provide rate-related, duration, and intensity information not available from traditional scaling. However, the utility of the methods must be weighed against the enhanced cost and complexity in data collection and analysis. In deciding whether to apply TI methods over conventional scaling, the sensory scientist should consider the following criteria:

(1) Is the attribute or system being studied known to change over time? Simply eating the food can often settle this issue; in many cases it is obvious.
(2) Will the products differ in sensory time course as a function of ingredients, processing, packaging, or other variables of interest?
(3) Will the time variation occur in such a way that it will probably not be captured by direct single ratings?
(4) Is some aspect of the temporal profile likely to be related to consumer acceptability?
(5) Does the added information provided by the technique outweigh any additional costs or time delays in panel training, data acquisition, and data analysis?

Obviously, when more answers are positive on these criteria, a stronger case can be made for choosing a TI method from the available set of sensory evaluation tools.

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