Designation: E 1909 – 97 (Reapproved 2003)

Standard Guide for Time-Intensity Evaluation of Sensory Attributes[1]

This standard is issued under the fixed designation E 1909; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers procedures for conducting and analyzing time-intensity (T-I) evaluations of products or other sensory stimuli. Time-intensity is the measurement of the intensity of a single sensory sensation over time in response to a single exposure to a product or other sensory stimulus.

1.2 This guide utilizes a specially trained panel to measure the intensity of a single continuous sensation during the time from initial exposure:

1.2.1 To its extinction,

1.2.2 To a specified intensity, or

1.2.3 To a predetermined limit of time.

1.3 Applications not covered in this guide include measuring:

1.3.1 Multiple sensations,

1.3.2 Multiple exposures within a single measurement, and

1.3.3 Qualitative or hedonic changes in the perceived sensation.

1.4 This guide includes protocols for the selection and training of judges, descriptions and use of physical data collection devices, and methods of data handling, summarization, and statistical analysis. Illustration of two different data handling and analysis approaches are included in the appendixes.

1.5 This guide is not applicable to measure product shelf life or stability that require evaluations at discrete time intervals.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 253 Terminology Relating to Sensory Evaluation of Materials and Products[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:* See Fig. 1.

3.1.1 *area after* I_{max}—post-peak area under the curve.

3.1.2 *area before* I_{max}—pre-peak area under the curve.

3.1.3 *AUC*—area under the curve.

3.1.4 I_{max} or peak intensity—maximum observed intensity during the time of measurement.

3.1.5 *perimeter*—measured distance of perimeter of area delineated by T-I curve.

3.1.6 *plateau time*—duration of peak intensity.

3.1.7 *rate of increase*—rate of intensity increase before peak intensity (slope).

3.1.8 *rate of decrease*—rate of intensity decrease after peak intensity (slope).

3.1.9 T_{dur} or duration time—time from onset of sensation until it can no longer be perceived (T_{ext} – T_{onset}).

3.1.10 T_{ext} or time to extinction—time from initial exposure to the stimulus (T_{init}) until it can no longer be perceived.

3.1.11 T_{init}—time of initial exposure to the stimulus, typically when the clock starts.

3.1.12 T_{max}—time to reach maximum intensity of the sensation after exposure to the stimulus.

3.1.13 T_{onset}—time point when the stimulus is first perceived after initial exposure to the stimulus.

3.1.14 T_{trun} or truncated time—time until a specified minimum intensity or until a pre-determined time point has been reached.

3.2 The graphical illustration of a typical time-intensity curve is shown in Fig. 1. The time increment may be seconds, minutes, hours, etc., depending upon the characteristic of the particular material under study.

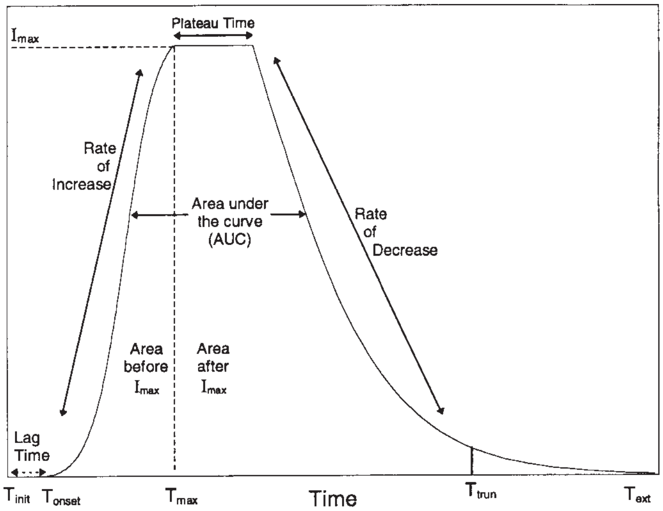
4. Summary of Guide

4.1 This guide describes procedures utilizing specially trained panelists to measure the intensity of a single sensory

[1] This guide is under the jurisdiction of ASTM Committee E18 on Sensory Evaluation of Materials and Products and is the direct responsibility of Subcommittee E18.03 on Sensory Theory and Statistics.

Current edition approved April 10, 2003. Published July 2003. Originally approved in 1997. Last previous edition approved in 1997 as E 1909–97.

[2] *Annual Book of ASTM Standards*, Vol 15.08.



NOTE 1—Based on a figure from Ref **(15)**.

FIG. 1 Representative Time-Intensity Curve with Selected Parameters Labeled

sensation as it changes with time and the possible approaches to collect and analyze such data. Details on specific procedures are given in Sections 6-9 of this guide. Examples of time-related evaluations are included in the Appendixes.

5. Significance and Use

5.1 The purpose of time-intensity measurements is to establish the pattern of development and decline of a particular sensory characteristic under study. T-I evaluations are applicable when measurements at a single time point (an averaging process) are not sufficient to distinguish products that have very different temporal characteristics. As pointed out by Lee and Pangborn **(1)**[3], "This averaging process results in the masking or complete loss of important information such as rate of onset of stimulation, time and duration of maximum intensity, rate of decay of perceived intensity, time of extinction, and total duration of the entire process."

5.2 Products rated similarly using traditional single point techniques of product profiling may provide very different temporal sensory experiences to the consumer. Acceptability of the product may be affected, and traditional descriptive methodology does not reflect the changes in an attribute's intensity over time.

5.3 T-I has applications for a variety of products. Examples include: food products, ranging from short-term sweetness in a beverage to long-term elasticity in chewing gum; personal care products, measuring the development and longevity of shampoo lather and the residual skin feel of a skin cream; household care products, monitoring the intensity of scents over time; pharmaceuticals, monitoring skin cooling after application of a topical analgesic. Auditory signals or visual changes in products can also be evaluated by the T-I technique.

6. Time-Intensity Panel Selection and Training

6.1 *Screening and Selection of Panelists*

6.1.1 Time-Intensity evaluation is a specialized type of descriptive analysis. Therefore, use of randomly selected, naive panelists is neither appropriate nor recommended. Panelists selected for Time-Intensity studies are screened as recommended for other descriptive methods (see STP 758 **(2)**). Use of panelists with previous descriptive training facilitates the T-I training because these panelists are competent in both recognizing and intensity scaling an attribute.

6.1.2 The goal of the selection process is to identify panelists who have the ability to:

6.1.2.1 Continually focus on a single sensory attribute,

6.1.2.2 Accurately identify and quantify a single sensory attribute within a simple or complex sample,

6.1.2.3 Accurately record changes in sensations as they occur,

6.1.2.4 Perform consistently,

6.1.2.5 Perform all test procedures with appropriate motor skills (for example, ability to chew gum while manipulating the input device to indicate the intensity of the mint flavor).

6.1.3 Compared to other descriptive methods, T-I panelists require more skills to complete the time-intensity task. Due to the complexity of the method and techniques involved, final selection of panelists may not occur until after completion of the training.

6.2 *Time-Intensity Panel Training*:

6.2.1 The purpose of T-I training is to demonstrate how to perform the physical, mental and psychological tasks associated with temporal profile method. Training begins with an orientation to the T-I method. Orientation to the method involves explanation and demonstration of the temporal nature of sensory properties, utilizing products having diverse temporal profiles. General time-intensity concepts may be illustrated by showing examples from alternate sensory modalities. Sound, light, odor, taste, touch/pressure or texture may all display temporal properties.

6.2.2 During training, panelists are thoroughly familiarized with all testing equipment and procedures.

6.2.3 The purpose of training samples is to demonstrate different onset, plateau, or duration characteristics. These are often best presented in contrasting pairs or sets. One example is a set of chewing gums, one with a fast flavor onset, another with a slower onset. Another example is a series of margarine products that demonstrate different textural properties, such as rate of melt.

6.2.4 References are samples that demonstrate an attribute at a given intensity. Use of references to calibrate intensity ratings occurs prior to the test. This is critical because in T-I analysis, attribute intensity is recorded without interruption during the test.

6.3 *Panel Performance Monitoring and Feedback*

6.3.1 Monitor panelist performance during the training and evaluation sessions. At the start of the study, determine an acceptable level of individual and group performance. This can include deviation around a scale value at a specified time point or similar indicator. STP 758 **(2)** provides statistical procedures suitable for monitoring panelist performance.

[3] The boldface numbers given in parentheses refer to a list of references at the end of the text.

6.3.2 Panelists should be able to demonstrate consistency in their evaluations. One approach is to measure reproducibility in selected curve parameters, for example, I_{max}, T_{max}, T_{ext}, of their individual T-I curves. However, consistency with other panelists is less likely than with general descriptive analysis, as each panelist tends to produce distinctive curve shapes. In T-I analysis, within-panelist consistency, particularly in their ability to communicate relative differences among samples, is more important than panelist-to-panelist agreement. See discussion in Section 9.

6.3.3 One parameter that should show some degree of agreement among the panelists is I_{max}, particularly if reference standards for intensity are being utilized. The I_{max} value can be used to compare panelist performance with an appropriate means-separation test, percent standard deviation, or other analysis methods commonly used in monitoring descriptive evaluations.

7. Panel Protocol

7.1 Specifics of the actual management of a time-intensity panel are highly dependent upon study objectives. The following topics represent major steps or considerations in the design and execution of time-intensity panels. It is assumed that basic panel training on the product of interest and selection of the appropriate data collection device have been completed (see Sections 6 and 8, respectively).

7.1.1 *Design Considerations*—Before the panel is conducted, the following sample, experimental design, and set-up issues are resolved:

7.1.1.1 The first consideration in designing a time-intensity panel is to determine the length of time for data collection. It can be relatively short, like the meltdown of a pat of butter when placed in the mouth, or relatively long, like the longevity of mint flavor in a chewing gum.

7.1.1.2 Knowing the expected duration, and designing the study to cover critical changes in a product is prerequisite to other design considerations. The number of sampling points and the time interval between points is set to capture the changes in an attribute at the time it occurs. Factors which may affect the duration of the attribute to be measured include: sample form (crystalline versus dilute solution of sugar), sample size (larger amount of sample versus smaller amount of sample), evaluation technique (dissolving versus chewing a hard candy), other materials (water hardness for soaps and shampoos).

7.1.2 The number of samples evaluated in a panel session is primarily dependent upon the duration of the time-intensity sensation. If the evaluation of a chewing gum is designed to measure mint flavor intensity changes over a 20 min period, one to two samples may be the maximum number panelists can evaluate without excessive physical or mental fatigue. Conversely, 5 to 6 potato chips may be evaluated for duration of crisp/crunchy attributes before fatigue sets in.

7.1.3 If the test is designed to measure the perception of an attribute to extinction, there is generally no need for lengthy waiting periods between samples. However, a longer waiting period is required when the perception of an attribute is affected by a preceding sample. Examples include: allowing mouth temperature to return to normal after ice cream evaluations, and recovery from numbing effects due to menthol or spices.

7.1.4 Sample presentation order may be randomized, fixed, balanced, or presented as an incomplete block, depending on study objectives. Typically, samples are presented in a balanced order to minimize position bias, context effects, etc. as recommended for most sensory evaluations. During training, samples may be presented in fixed order (that is, all panelists see the same samples in the same order of presentation), to facilitate discussion and learning.

7.2 *Data Collection Considerations*—In any time-intensity experiment, regardless of the type of data collection device used, the rate at which information is collected must be determined. Data recording intervals are set to capture maximum/critical change on a product's profile, with intensity ratings collected at various time points depending on the study objective (see Sections 8 and 9).

7.3 *Sample Preparation*—As with any sensory evaluation, sample preparation and presentation for T-I analysis need to be controlled to eliminate extraneous effects. Recommended guidelines are to be followed (Manual 26)**(3)**.

7.3.1 *Reference Samples*—If appropriate in the test design, use of reference samples is recommended. References are evaluated prior to test samples, so that test sample evaluation is conducted without interruption. References are evaluated by the same technique as the test samples and may be used to specify an attribute's intensity at a specific point in time.

7.3.2 *Conditioning Sample*—Use of a conditioning sample, presented prior to the actual test sample, can be used to calibrate panelists to the same sensation, and to some extent, to control first position bias or context effects. Consideration should be given to adaptation, carryover, and fatigue in deciding whether or not to use a conditioning sample.

7.3.3 *Inter-Stimulus Procedures*—Specify whether panelists are to rinse, re-taste reference standards, or use a palate cleanser such as a cracker, celery, etc. between samples.

7.4 *Evaluation Procedures*:

7.4.1 Evaluation begins as soon as the stimulus is introduced to the panelist, for example, when the sample is applied, tasted, or smelled. The evaluation is completed upon reaching a predetermined time limit, intensity, or extinction of the sensation.

7.4.2 Standardized evaluation procedures such as the force and frequency of manipulations (for example, chews per second of a cookie, rubs of a hand lotion, or whether to expectorate or swallow) must be specified and incorporated into the panel training and test procedures to assure all panelists receive the same sample stimulus.

7.5 *Other Panel Protocol Considerations*:

7.5.1 *Testing Environment*—Follow recommended guidelines for physical testing facilities in STP 913 **(4)**.

8. Data Collection Techniques

8.1 *Introduction*—The two modes of data collection in time-intensity evaluation are cued and real-time. With cued techniques, panelists are instructed to report their responses at specific, predetermined points in time during the evaluation. With real-time techniques, panelists report their responses continuously over time during the evaluation. Selection of one technique over the other depends on such issues as the goals of the study, the desired time points, available resources, and economic considerations.

8.2 *Cued Techniques*:

8.2.1 This mode of data collection uses an external device or a person other than a panelist to provide an audible and/or a visual cue at the time when a response is required. Examples of cueing devices are: stop watches, visual or audible metronomes, or both, other beeping or blinking devices with adjustable timing, and computers.

8.2.2 The main advantage of cued techniques is the simplicity of the task for the panelists. Also, cued techniques often are less costly than real-time techniques. Limitations of this mode are low precision of data when short time intervals are used, possible distraction or biasing of the panelists by the cueing device and, when applicable, by viewing of previous ratings.

8.3 *Real-Time Techniques*:

8.3.1 This mode of data collection uses an external device that allows the panelists to report their responses continuously during the evaluations. Examples of such devices include strip-chart recorders and computers. With a strip-chart recorder, a panelist moves a pen along a straight edge fixed over a moving strip-chart to indicate the intensity of the attribute at each instant in time. The speed of the recorder establishes the time axis. Similarly, with computers, a scale is displayed on the computer screen and the panelist manipulates an input device, such as a light-pen, joystick, or mouse, to position the computer's cursor on the scale to indicate the intensity of the attribute at each instant in time. The on-board clock of the computer is used to establish the time axis.

8.3.2 Several options are available for recording data obtained using real-time techniques. One approach is to measure reported intensities at a fixed number of predetermined time-points—for example, at selected locations along the strip-chart, or by instructing the computer to only record or store data at selected time-points. (Note that the panelist would not be aware of the time-points actually recorded for analysis.) Another approach is to record all the data obtained in a real-time evaluation. For example, the curve formed on the strip-chart could be recorded using a digitizer, or the computer software could be instructed to record a panelist's intensity readings as frequently as the computer allows.

8.3.3 The main advantages of real-time techniques are the flexibility afforded the analyst for controlling the collection intervals and by having all of the panelists' readings available for numerical analysis and interpretation. Another advantage of most real-time techniques is that they do not allow the panelist to view previously reported intensity values, thus eliminating the potential bias resulting from observations of the completed portion of the evolving T-I curve. Disadvantages of real-time techniques are more cumbersome or complex hardware requirements, the need for more sophisticated data handling systems, and typically higher costs.

9. Data Handling, Analysis, and Summarization

9.1 *Introduction*:

9.1.1 There are two aspects of T-I data that present challenges not typically encountered in other types of sensory data.

9.1.2 First, instead of a single response associated with each stimulus, T-I data consists of a collection of responses consisting of the intensity at each time point. The multiple values arising from T-I data can either be handled directly by special statistical analysis approaches or by data handling steps performed prior to the statistical analysis.

9.1.3 Second, T-I data typically exhibits greater panelist to panelist variability than found in other methods. This is seen in time-intensity curve shapes, sometimes referred to as "curve signatures", that are either unique for each panelist or that fall into various broad categories of shapes. Part of this variability in curve shape can be reduced by training and standardization of techniques, but it is generally believed that it cannot be completely eliminated.

9.1.4 The following section discusses several data handling techniques for T-I data. It is important to understand that there have not been a sufficient number of critically reviewed published studies to warrant setting specific guidelines or recommendations.

9.2 *Data Handling*—Several data handling techniques can be used to process the multiple-valued nature of T-I data prior to analysis. These techniques include: collecting only data relevant to the study objective, eliminating redundant data, removing data contributing to bias, smoothing noisy data, or summarizing the data by extracting curve features of interest.

9.2.1 Study objectives can determine which data points are of interest. For example, if the purpose of the study only requires information on the time to maximum intensity, then only this specific data could be collected.

9.2.2 An example of redundant data would be the collection of response values more frequently than the response is changing. This would result in a response plateau that may not be of interest in the study. In this case, the data between the start and the end of the plateau can simply be deleted from the data file, leaving two points to define the plateau.

9.2.3 Bias or data error arises when the response is influenced by factors other than the stimulus itself. Examples of such factors include variations in panelist evaluation techniques, such as expectoration prior to the designated expectoration time. If it becomes known that such actions tend to result in characteristic response patterns, that is, an extraneous curve peak, then the associated response data could be removed prior to analysis.

9.2.4 If the response data do not exhibit regular or smooth trends, but rather has noisy fluctuations around a general trend, the data can be processed by "smoothing" algorithms. Such algorithms replace the original data with transformed values that reflect the trend, but do not include the noisy fluctuations **(5)**. The resulting smoothed data are typically what is used in any further analyses.

9.2.5 The T-I data can also be reduced to just a set of key curve characteristics. Each characteristic, or parameter, represents a specific feature of the time-intensity curve. Commonly used parameters include the following (see Section 3 for definitions):

9.2.5.1 I_{max},

9.2.5.2 T_{onset},

9.2.5.3 T_{max},

9.2.5.4 $T_{plateau}$,

9.2.5.5 T_{ext},

9.2.5.6 Area under the whole, or part, of the curve,

9.2.5.7 Slopes, or rates of intensity increase or decrease, and

9.2.5.8 Other parameters defined as needed, such as curve perimeter or curve shape.

9.3 *Data Analysis*:

9.3.1 Several options for the analysis of T-I data are described in the sections given below. It is important to note that not every method is applicable to every research situation. The methods vary in their complexity and the circumstances for which they are best suited. No matter what method is used it remains important to ensure that the data are accurate, that the analysis is consistent with how the study was designed, and that analysis assumptions are met.

9.3.2 Since complete details on the analyses are not given below, statistical advice or references should be utilized as needed.

9.3.3 A preliminary step for most analyses should be a visual inspection of the individual panelist time-intensity graphs. This involves plotting out specific curves to identify situations described in 9.2.1 and 9.2.2. Visual inspection will also help in making decisions regarding the most appropriate data analysis.

9.3.4 If curve parameters (see 9.2.5) are used as the "raw data" for the statistical analysis, conventional statistical techniques can be used. For example, analysis of variance (ANOVA) may be performed to compare means and form confidence intervals (see Appendix X1). These ANOVA models may include a term, or factor, for judge effects. The judge term will often be statistically significant as it has generally been found that judge signatures remain, even after extensive training (see 9.1).

9.3.4.1 Multivariate analysis of variance (MANOVA) could also be performed on the set of all curve parameters. Other multivariate methods can also be used, such as performing a principal components analysis on selected curve parameters **(6)**. The principal component scores are then analyzed by analysis of variance or other methods.

9.3.4.2 The advantage of using any of these multivariate methods over the univariate ANOVAs is that patterns of differences can be detected. For example, modest differences in T_{max}, $T_{plateau}$, falling AUC, and T_{ext} may all give rise to one stimulus differing from another when looked at jointly, that is, using a multivariate method. The general pattern of longer-lasting response intensity may not be significant when each of these parameters is analyzed separately.

9.3.5 If the data consist of only a relatively small number of time points, then repeated measures analysis of variance with time and time by stimulus as model factors can be utilized. The advantage of this approach over analyzing curve parameters is that the parameter estimates may be quite imprecise when there are few time points. For example, if sweet intensity was collected on a gum only every minute, then T_{max} cannot be more precise than a minute. This approach requires examining the time by stimulus interaction term in order to assess and compare stimulus effects.

9.3.5.1 When the number of time points becomes large, say greater than eight, examining such an interaction becomes unwieldy. In addition, assumptions on how time points correlate to each other, required for what is called the "univariate approach," may not be met, particularly as the number of time points increases. This can sometimes be handled by modeling the variance-covariance structure using general linear mixed model methods **(7)**.

9.3.5.2 Alternatives to a repeated measures analysis would be either a multivariate analysis of variance (MANOVA) on the set of intensity values or separate analyses at each time point. As the number of time points increase both techniques would become increasingly unwieldy. The MANOVA would also require a large amount of data, that is, judges, in order to be feasible.

9.3.6 Analyses based on time-to-event models **(8)** can also be used for time intensity data if there is a specific time parameter of interest or if the only data recorded were time parameters, such as T_{onset}, T_{max}, or T_{ext}. These models are sometimes referred to as either "survival models" in the medical field or "failure models" in manufacturing. An example "event" for T-I data would be the time when the sensation was no longer perceived, that is, T_{ext}. The collection of event times would then be the data analyzed by these techniques.

9.3.6.1 Methods that do not rely on a particular time model, that is non-parameteric methods, include the method due to Kaplan-Meier, also called the product-limit method. This approach estimates the odds of the event occurring at any given time point. For example, the particular time point when there is a 50 % chance of reaching the I_{max} could be estimated.

9.3.6.2 The advantages of using time-to-event methods depend partly on the nature of the data. The method can handle what is called" censored" data, that is, data that were truncated. For example, suppose that time-intensity values were collected for only the first two minutes, but extinction of the intensity for several panelists exceeded two minutes. In this case their T_{ext} values would be "censored" at two minutes. Standard ANOVA does not handle censored data. In addition, the event times may not satisfy other ANOVA assumptions, such as normality, that the time-to-event model does not require.

9.3.7 A method that is not particularly applicable to T-I data is autoregressive integrated moving average (ARIMA) time series models introduced by Box and Jenkins **(9)**. This methodology is primarily used for forecasting and process control. Such applications are not the goal of T-I research. Furthermore, ARIMA models require that the time interval be fixed, that is, equally spaced, but T-I data are often recorded or collected with varying time intervals.

9.4 *Curve Summarization*—Since a key aspect of T-I studies is that data are collected over time, it is clearly natural to display the data with the time dimension included. Although individual time intensity curves may be plotted, it is also very useful to be able to summarize what the panel as a whole says about a given stimulus. This is particularly useful to visualize sample differences. Several techniques for summarizing individual T-I curves into a panel consensus curve are described below.

9.4.1 A natural, though simplistic, approach to combining individual time-intensity curves is to average the intensity responses at each time point, and then plot these mean values as the summarized curve. This approach will often introduce distortions unless each individual curve follows a highly similar time course pattern.

9.4.1.1 An example using just two panelists is shown in Fig. 2, below. One panelist reaches a response extinction point (T_{ext}) at 40 s and another panelist at 60 s. Although, in this two-judge example, the mean extinction time is 50 s, the plot of the simple averages at each time point would show the "consensus curve" falling to zero at 60 s. This is because the mean of the panelists' ratings will continue to be non-zero until *all* judges hit zero. In addition, even though both judges have a distinct plateau time, the mean curve does not because the plateau times of the two judges do not happen to overlap.

9.4.2 A simple approach that avoids the distortions of averaging is to connect various key curve parameters with straight line segments. The points so connected would typically be the parameters averaged over the panelists.

9.4.2.1 For example, the average onset time, peak intensity, time to peak intensity, peak duration time, and extinction time, can be connected. Such a curve, though rough, would be completely consistent with the results of conventional statistical analysis on the curve parameters (see Fig. X1.2). However, as with any curve that summarizes the entire panel, this curve is not likely to match any given panelist's typical response.

9.4.3 A curve averaging technique that creates a common intensity range for the T-I curves was first reported by Overbosch et al. **(10)**, and involves four steps:

9.4.3.1 Normalize or re-scale the intensities of each curve to the geometric mean of the maximum intensities (I_{max}),

9.4.3.2 Segment each curve into "*n*" equal steps in time (20 is recommended) both before and after the point of maximum intensity,

9.4.3.3 Calculate the geometric mean on the normalized intensities for each time segment (interpolate), and

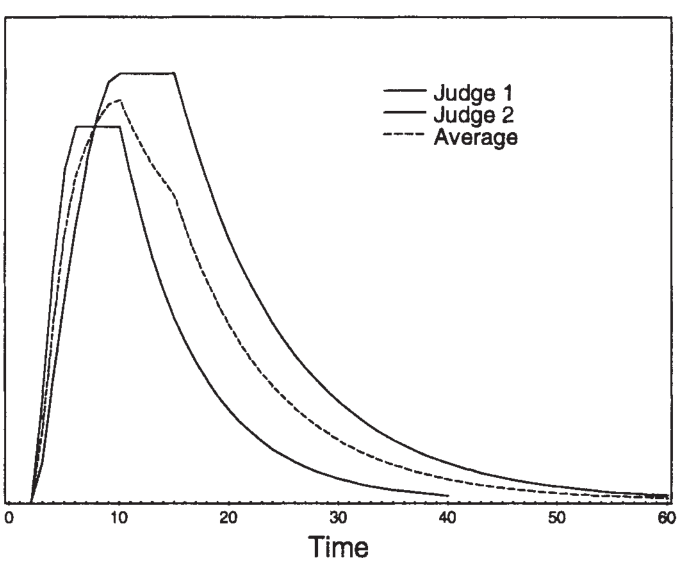


FIG. 2 Example Time-Intensity Curves Showing Two Judge Curves and the Result of "Simple" Averaging

9.4.3.4 Plot the normalized, geometric mean intensities over the time steps.

9.4.4 Liu and MacFie **(11)** suggested an enhancement to the Overbosch approach that used more curve parameters by adjusting the time axis as well (see Fig. X1.3), and consists of five steps:

9.4.4.1 Normalize the intensities of each curve to the panel mean maximum intensity,

9.4.4.2 Standardize the times of each curve in the interval T_{onset} to T_{max} to lie within the corresponding panel averages, likewise for the interval T_{max} to T_{ext}, with the plateau time mapped to the mean as well,

9.4.4.3 Split the interval from the panel mean T_{onset} to T_{max} and from T_{max} to T_{ext} into "*n*" equal time points (20 is recommended); separately for each curve, estimate the intensity at these standardized time points by linear interpolation,

9.4.4.4 Calculate the average of the interpolated intensities at each of the common time points, and then

9.4.4.5 Plot the averaged intensities versus time.

9.4.4.6 In either approach, however, the normalization of the data can result in misleading information. For example, forcing the curves to fit within the panel average I_{max} intensity and time ranges will tend to shrink the AUC of judges above the panel mean and inflate the AUC of judges below the mean. After curve averaging, the AUC of the final curve will not generally match the panel average AUC. It may even occur that the AUCs of the summarized curves are not in the same rank order as the panel average AUCs; that is, the stimuli with the largest panel mean AUC may not have the largest AUC among the summarized curves. If AUC differences are not relevant to the objectives of the project, then this artifact of the method would not pose a problem. In general, when using these summarization methods, it is advisable to make sure that the summarized curves are consistent with the conclusions of the data analysis.

9.4.5 Curves can be summarized by modeling the shape of the time intensity curve **(12, 13)**. In this case, a consensus curve is formed by plotting the model predictions. The model predictions are calculated using the estimated panel parameters from the model fit separately to each stimulus.

9.4.5.1 When using a modeling technique, the ideal approach would be to fit a theoretical equation that describes the mechanisms at work. Some researchers have used exponential growth and decay models fit to the rising and falling portions of the T-I curve, respectively. Further research would need to be done to establish what mechanistic models explain T-I data.

9.4.5.2 If a theoretical model is not available, empirical model fitting can be done. This might involve fitting separate regression equations to natural divisions of the time axis. For example, a separate regression could be performed on the time interval from T_{onset} to T_{max}, from T_{max} to T_{max}+ $T_{plateau}$ and from T_{max}+ $T_{plateau}$ to T_{ext}. The plateau interval is essentially a constant. The other intervals would require regressions of a linear, quadratic, or even higher order, depending upon the shape complexity of the T-I curves.

9.4.6 Van Buuren introduced **(14)** and Dijksterhuis **(15)** further developed a procedure using principal components analysis (PCA) to summarize curves into "principal curves."

The PCA is performed with the time points as observations and the judge curves as variables.

9.4.6.1 In this approach, the first principal curve is the weighted average that best summarizes the entire collection of judge curves. Subsequent principal curves account for variability not already handled by earlier ones.

9.4.6.2 The PCA loadings can be examined to determined how specific curves influenced a given principal curve. This might be used to spot panelist subgroups or outlying judges.

9.4.6.3 Principal curves differ from the simple average method because the weights (PCA loadings) are constructed to capture the most information possible. It is unclear, however, whether the principal curves are free of the distortions discussed in 9.4.1, nor have they been directly compared to the other methods discussed above.

APPENDIXES

(Nonmandatory Information)

X1. TIME-INTENSITY: SWEETENERS IN A BEVERAGE

X1.1 Consumer evaluations of two lemonade powdered soft drinks, one sweetened with sucrose and one with aspartame, showed varied comments about the sweetness of the beverages, despite every attempt to make the two beverages equivalent in sweetness intensity. The product developer wanted to understand how the sweet taste of aspartame compared to the sucrose control in the formulation. A time-intensity evaluation was conducted to fully document the development and decline of the sweet taste.

X1.2 Ten experienced descriptive flavor panelists were calibrated in the quantification of sweetness intensity and then trained in the usage of a computerized data collection device and procedures. Beverage samples were prepared containing levels of sweetener previously determined by multiple paired comparison testing versus a sucrose standard to provide equivalent sweetness intensities to the sucrose standard. Reference standards for sweetness intensity were also prepared to deliver a range of sweetness intensity values (2, 5, 7.5, and 10 on a 15-unit line scale.)

X1.3 Each panelist received the references, plus coded 15-mL samples of the two sweetened beverages. Panelists first tasted the sweet references, then rinsed well with water. They then used a mouse device to position the cursor over the zero point on the scale, and clicked the mouse button as the entire first sample was placed in their mouth to initiate the timing. Sweetness intensity was tracked by moving the cursor along the line scale using the mouse. At 10 to 15 s an on-screen message instructed the panelists to expectorate. Evaluation of sweetness intensity continued until no sweetness was perceived and the panelists returned the cursor to zero, or until the preset time duration of 60 s was reached. This procedure was followed for the second sample after a waiting time of 2 min. Three time-intensity sessions were held to collect three replicate evaluations of the two beverages.

X1.4 The preset time points for data collection were more frequent initially, in order to capture the time period where the greatest change in intensity was expected. Intensity data was collected every 0.1 s through the first second, every 0.2 s from 1 to 3 s, every 0.3 s from 3 to 6 s, every 1 s from 6 to 26 s, and every 3 s until 60 s elapses. An example of the complete data set collected from a single judge (Judge Number 1) are shown in Table X1.1.

X1.5 As is common to T-I data, the curves generated from each judge were varied (see Section 9). Fig. X1.1 illustrates the curves generated from three judges during replication one. Some of the shape differences among these judges are: Judge 1 showed a rapid rise in intensity, with little or no plateau, Judge 2 had a slightly slower rise with a definite plateau, and Judge 3 showed the most gradual rise, but no plateauing.

X1.6 Data analysis of selected curve parameters was chosen as the means to understand the T-I differences between the sweeteners. The parameters selected are shown in Table X1.2 for three of the ten judges. The mean values for each of these ten parameters are listed in Table X1.3. Standard analysis of variance was applied, and the *p*-values listed show some significant differences at the 5 and 10 % significance level. Specifically, the differences between the sweeteners was in the latter half of the curve, with aspartame exhibiting a slower decline and greater duration of sweet taste than sucrose.

X1.7 Two methods of curve summarization were completed. The first was the connecting of selected curve parameters with straight lines. Fig. X1.2 shows the connecting of mean intensity values at T_{onset}, T_{max}, T_{max}+ plateau time, and T_{ext}. Fig. X1.3 illustrates the curve summarization technique developed by Liu and MacFie **(11)**. With this simple data set, either plot is sufficient to illustrate the key differences between the sweeteners.

X1.8 The I_{max} of the two sweeteners was noted to be the same, which concurs with previous testing for equivalent sweetness intensity. However, the T-I method was able to capture the differences in the linger of the sweet taste after I_{max} was reached. This information proved useful in explaining the variable consumer response to the lemonade's sweetness, and will guide further reformulation efforts.

TABLE X1.1 Time-Intensity Data on Two Sweeteners in Lemonade for Judge Number 1, Replication 1

Time (seconds)	Intensity for Sucrose	Intensity for APM
0.1	0.00	0.00
0.2	0.00	0.00
0.3	0.00	0.00
0.4	0.00	0.00
0.5	0.00	0.00
0.6	0.00	0.00
0.7	0.00	0.00
0.8	0.00	0.00
0.9	0.00	0.00
1.0	0.00	0.00
1.2	0.00	0.00
1.4	0.00	0.00
1.6	0.00	0.00
1.8	0.00	0.25
2.0	0.00	0.25
2.2	0.74	0.25
2.4	1.72	0.25
2.6	2.21	0.49
2.8	2.46	0.74
3.0	2.70	0.98
3.3	3.44	1.72
3.6	3.93	2.46
3.9	4.67	2.95
4.2	5.16	3.44
4.5	5.90	4.18
4.8	6.39	4.43
5.1	7.38	5.16
5.4	7.62	5.66
5.7	7.87	5.66
6.0	8.11	5.90
7.0	8.61	6.64
8.0	8.85	7.87
9.0	8.36	8.36
10.0	8.11	8.85
11.0	7.87	9.10
12.0	6.89	9.10
13.0	5.90	9.10
14.0	4.92	9.10
15.0	4.43	8.61
16.0	3.69	8.61
17.0	2.95	8.11
18.0	2.46	8.11
19.0	1.97	8.11
20.0	1.23	8.11
21.0	0.49	7.87
22.0	...	7.62
23.0	...	7.13
24.0	...	6.89
25.0	...	6.64
26.0	...	6.64
29.0	...	5.41
32.0	...	4.92
35.0	...	3.44
38.0	...	3.44
41.0	...	3.44
44.0	...	1.97
47.0	...	1.48
50.0	...	1.23
53.0	...	1.23
56.0	...	1.23

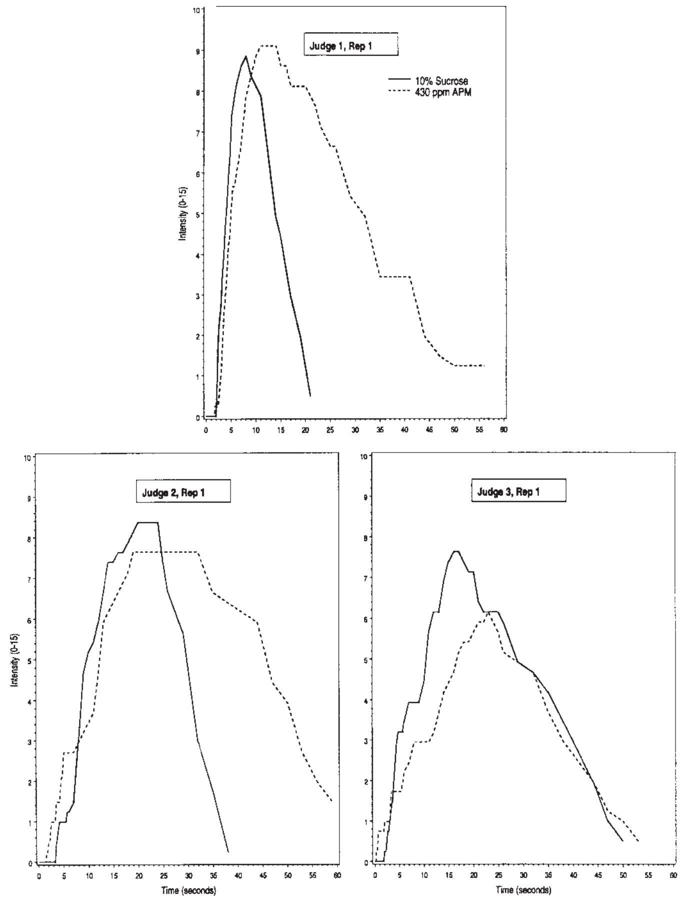


FIG. X1.1 T-I Curves for Rep 1 of Judges 1, 2, and 3

TABLE X1.2 Time-Intensity Curve Parameters by Sample for Judge's 1, 2, and 3, and Each Replication

Judge	Rep	T_{onset}	T_{max}	T_{plat}	T_{ext}	I_{max}	Area before I_{max}	Area after I_{max}	Area (total)	Rate of Increase	Rate of Decrease
10 % Sucrose in Lemonade											
01	1	2.2	8.0	0.0	21.0	8.9	36.1	63.7	99.8	2.46	0.74
	2	2.8	8.0	1.0	26.0	10.1	29.3	93.3	122.6	3.28	1.72
	3	1.8	10.0	0.0	35.0	8.4	40.3	139.4	179.7	0.82	0.41
02	1	3.6	20.0	4.0	38.0	8.4	85.4	90.0	175.4	1.72	0.90
	2	4.8	17.0	2.0	53.0	7.1	50.4	161.4	211.8	0.49	0.41
	3	1.2	12.0	5.0	68.0	7.9	40.0	141.1	181.2	2.21	0.74
03	1	2.0	16.0	1.0	50.0	7.6	62.1	145.9	208.0	0.49	0.25
	2	1.6	17.0	2.0	41.0	5.2	36.7	72.9	109.6	0.74	0.41
	3	3.6	16.0	0.0	53.0	7.9	89.5	151.0	240.4	0.98	0.57
430 ppm APM in Lemonade											
Judge	Rep	T_{onset}	T_{max}	T_{plat}	T_{ext}	I_{max}	Area before I_{max}	Area after I_{max}	Area (total)	Rate of Increase	Rate of Decrease
01	1	1.8	11.0	3.0	56.0	9.1	51.5	214.3	265.8	2.46	0.49
	2	0.4	6.0	0.0	22.0	10.1	32.7	99.0	131.7	1.23	0.25
	3	1.4	7.0	0.0	26.0	9.8	29.2	109.9	139.1	2.46	1.23
02	1	1.6	19.0	13.0	80.0	7.6	71.7	246.3	318.0	0.98	0.41
	2	0.7	7.0	0.0	83.0	6.9	59.4	214.9	274.3	3.28	0.08
	3	0.8	17.0	2.0	80.0	8.1	80.9	294.0	374.9	1.23	0.41
03	1	0.3	23.0	0.0	53.0	6.1	79.4	95.0	174.4	0.25	0.25
	2	2.0	15.0	2.0	101.0	6.1	48.5	257.3	305.8	0.82	0.16
	3	1.4	11.0	2.0	68.0	4.9	30.0	173.4	203.4	0.82	0.08

TABLE X1.3 T-I Curve Parameter Analysis Summary Panel Means by Sample with Significance Test (p-Value)

T-I Parameter	10 % Sucrose in Lemonade	430 ppm APM in Lemonade	*p*-value
T_{onset}	2.0	1.5	0.1000
T_{max}	11.0	11.7	0.4297
$T_{plateau}$	2.7	2.3	0.8191
T_{ext}	46.6	62.8	0.0170^{A}
I_{max}	7.7	7.7	0.9576
Area before I_{max}	42.1	50.0	0.1504
Area after I_{max}	152.5	192.9	0.0604^{B}
Area (total)	194.6	243.0	0.0438^{A}
Rate of Increase	2.24	2.12	0.7428
Rate of Decrease	–0.57	–0.39	0.0472^{A}

[A] Statistically significant difference between sample means at the 10 % significance level.
[B] Statistically significant difference between sample means at the 5 % significance level.

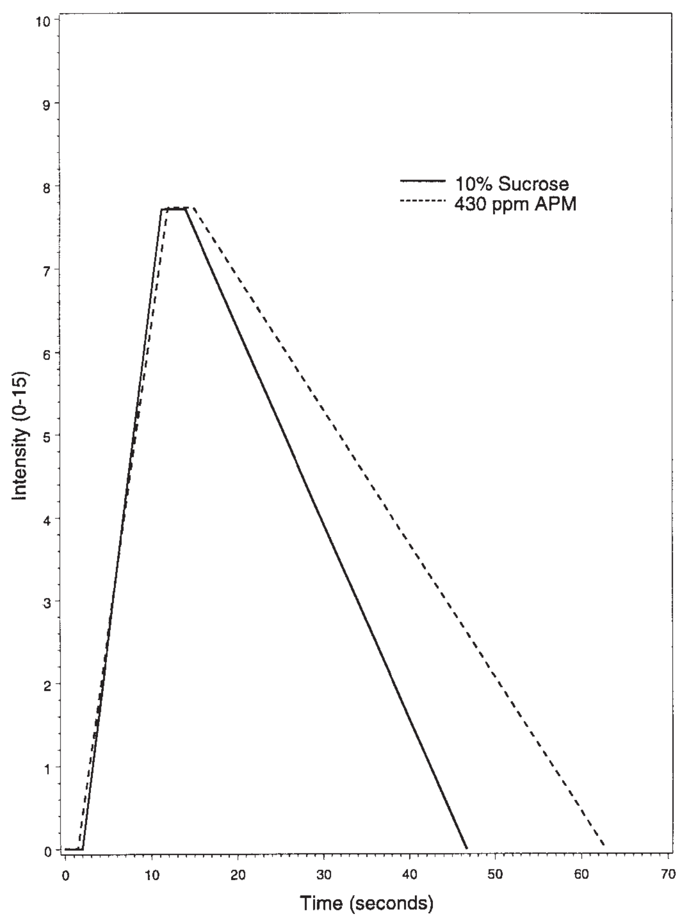


FIG. X1.2 Panel Summarized T-I Curves by Connecting Key Curve Parameters

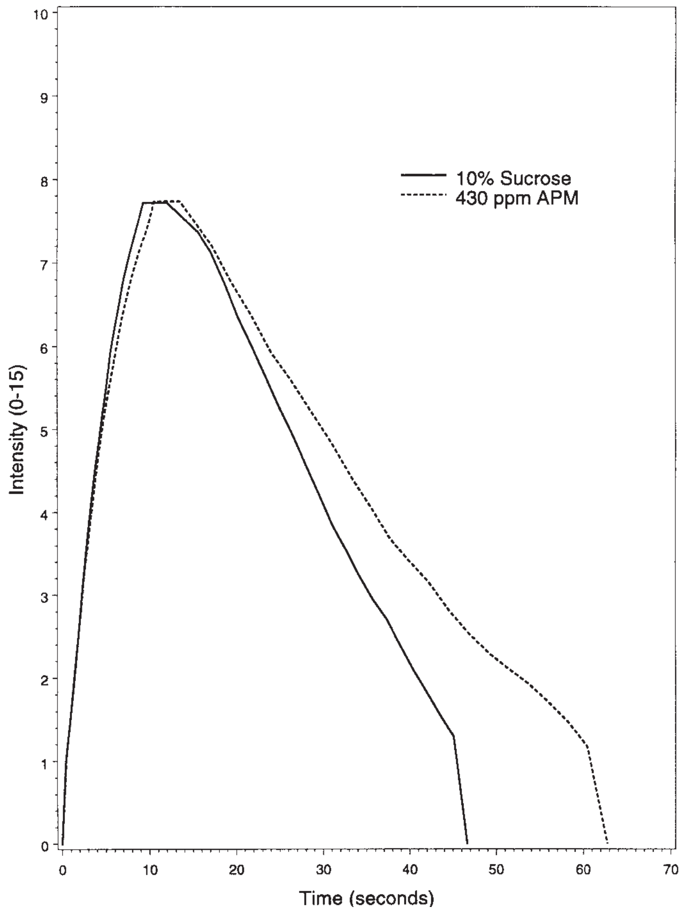


FIG. X1.3 Panel Summarized T-I Curves by the Method of Liu and MacFie (11)

X2. TIME-INTENSITY—AMOUNT OF CHEWINESS IN EIGHT FOODS

X2.1 During the training of a descriptive panel, the question arose as to the time point at which various texture attributes are or should be evaluated. A time-intensity study was conducted to help understand the temporal properties of these texture attributes. Chewiness, was an attribute that was of particular concern, as it is a combination of other attributes, including hardness, cohesiveness of mass, and springiness. For this study, Chewiness was defined as the amount of work, effort, or force needed to chew at a given moment in time. The samples were selected to represent broad differences in physical structure **(17)**:

X2.1.1 Frankfurters,
X2.1.2 Caramel candy,
X2.1.3 Raw carrot,
X2.1.4 Corn muffin,
X2.1.5 Gelatin Dessert,
X2.1.6 Gum Drop,
X2.1.7 Rye bread, and
X2.1.8 Tootsie Roll.

X2.2 Five trained panelists evaluated the samples over nine sessions. Four panelists completed three replications per sample. One panelist completed only two replications. Each panelist evaluated one of each sample per session for Chewiness. Data were collected using a computerized data collection device, a light pen moving across a horizontal scale on a computer screen. The program converted each time-intensity curve into ten parameters: AUC, T_{max}, I_{max}, T_{init}, T_{ext}, T_{dur}, rate of increase (Rate1), area before I_{max}(Area1), rate of decrease (Rate2), and area after I_{max}(Area2), as shown in Fig. X2.1.

X2.3 The statistical analysis of time-intensity data provides additional opportunities and challenges compared to single point sensory data collection. Numerous techniques can be applied to the data. In this case, six steps were used to analyze the curve parameters:

X2.3.1 Eliminate redundant attributes,
X2.3.2 Screen for outliers,
X2.3.3 Transform parameters,
X2.3.4 Adjust for panelists effects,
X2.3.5 Reduce data using principal components, and
X2.3.6 Test for sample differences over original parameters and principal components.

X2.4 *Eliminate Redundant Attributes*—The parameter

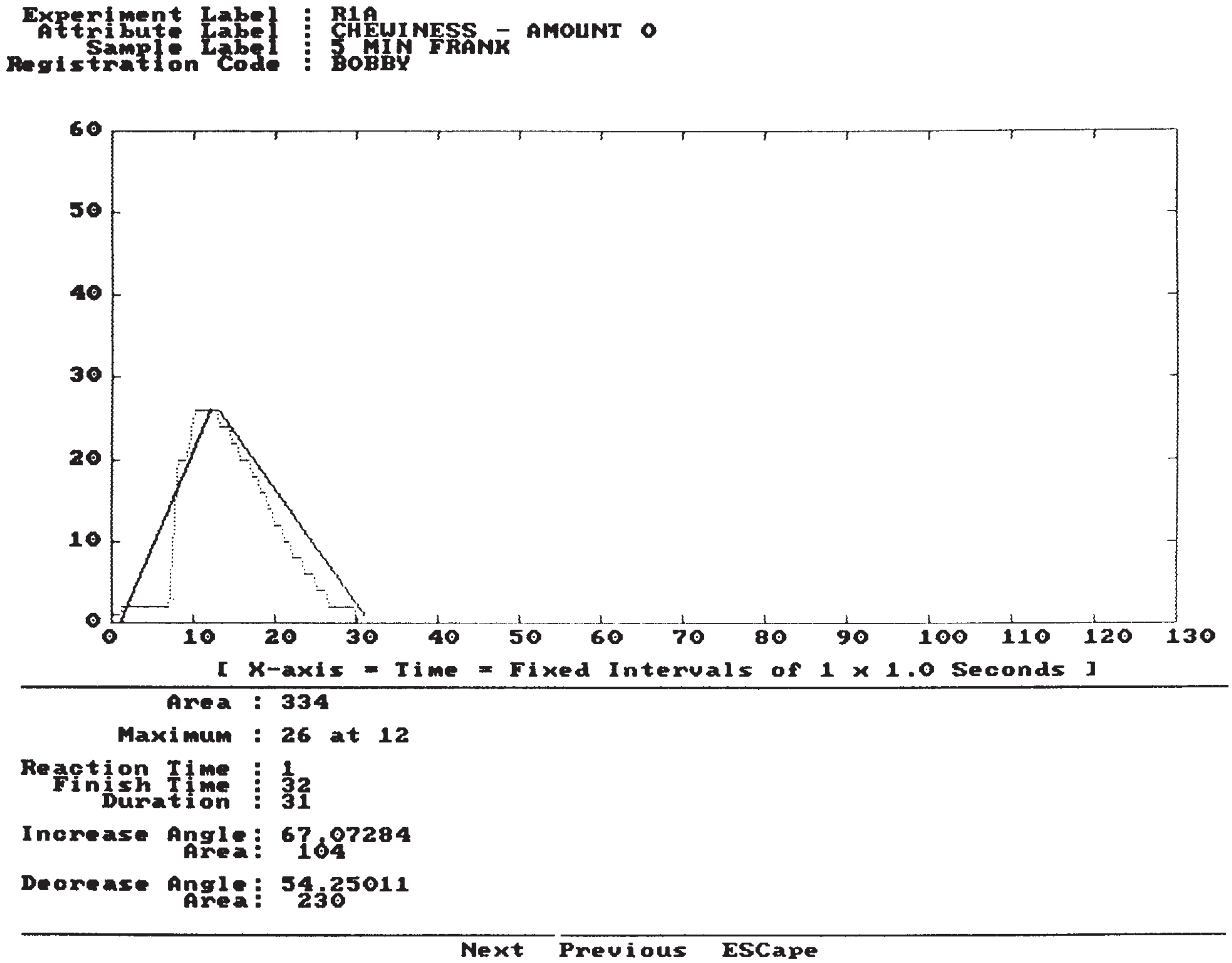


FIG. X2.1 Analyze Time Intensity Information

Area2 is equivalent to AUC-Areal and T_{dur} is equivalent to T_{ext} minus T_{onset}. Thus, these two parameters were eliminated from the analysis.

X2.5 *Screen for Outliers*—Box plots were used to look for T-I curves that resulted in curve parameters that were outliers. Fig. X2.2 shows that Curves 1, 2, and 47 are outliers on two or more curve parameters, I_{max}, T_{ext}, and Rate1. These particular curve parameters were excluded from the remaining analysis.

X2.6 *Transform Parameters*—Assuring the normality of parameters is advisable for the evaluation of T-I parameters. Area and rate data more often require transformation than typical sensory data. Normal Q-Q plots were used to check deviations from normal distribution and to suggest transformations. Plots of AUC, Area1, T_{max}, T_{init}, and T_{ext} indicated that all required log e transformation. The plot of Rate1 suggested the use of the Aranda-Ordax transformation for bounded scales. These transformations successfully achieved normally distributed curves. The original and transformed plots for AUC, T_{max}, and Rate1 are shown in Fig. X2.3 and Fig. X2.4 as examples.

X2.7 *Adjust for Panelist-Effects*—Individual panelists typically had characteristic time-intensity curve parameters. These panelist-effects should be removed, particularly for multivariate work to maximize the effectiveness of finding differences among the samples, rather than differences among the panelists. To do this, the scores for each panelist were normalized by subtracting the corresponding panelist parameter mean from them.

X2.8 *Reduce Data Using Principal Components*—Principal component analysis was used as a data reduction technique. Three principal components were used based on the criteria of an eigen value greater than one, Table X2.1. The first principal component, PC1, was related to the size of the curve (AUC, I_{max}, T_{ext}, and Rate1, see Table X2.2, highlighted loadings). The second principal component, PC2, was related to Rate1 and T_{max}. The third principal component, PC3, was related to Rate2. Fig. X2.5 shows a plot of PC1 versus PC2. The carrot, tootsie roll, and caramel samples were grouped and were associated with Log_e (T_{ext}), Log_e (Area1), Log_e (Area), and I_{max}. Rye bread, corn bread, and gelatin were grouped and were opposite those same parameters. The frank and gum drop fell in between those groups.

X2.9 *Test for Sample Differences Over Original Parameters and Principal Components*—Analysis of variance was conducted on the original parameters and on the first three

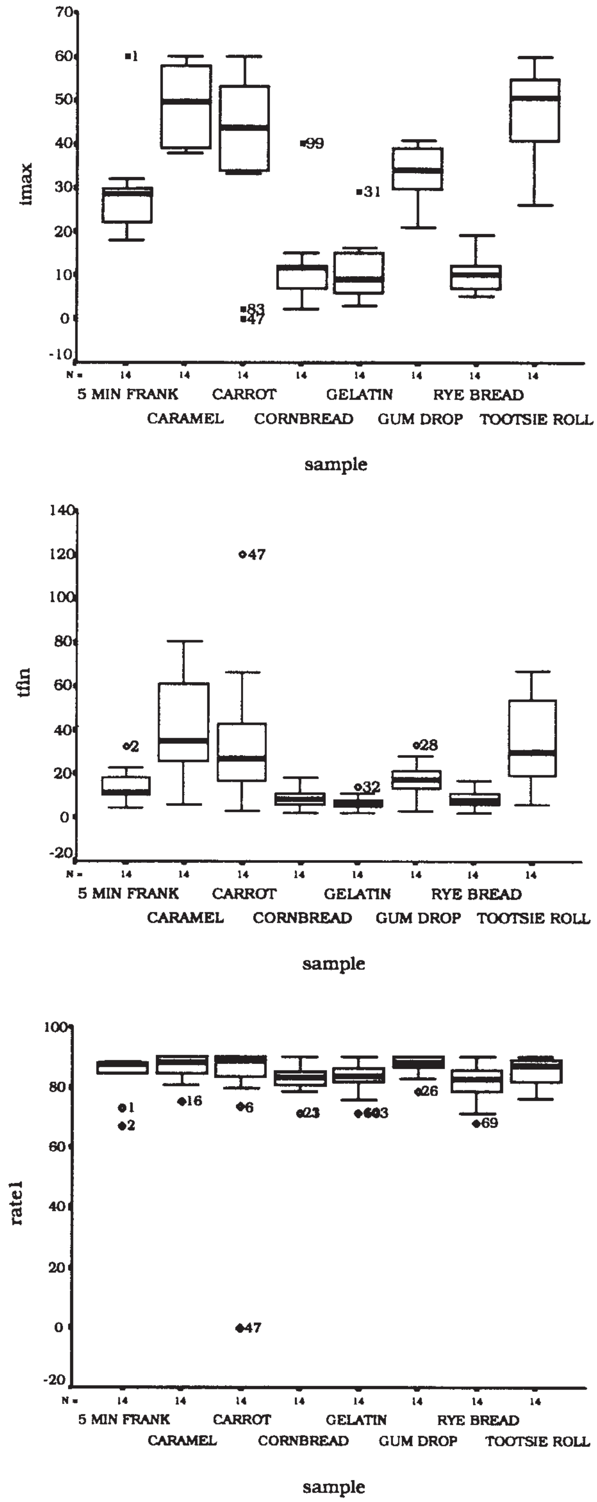


FIG. X2.2 Box Plots for Outliers

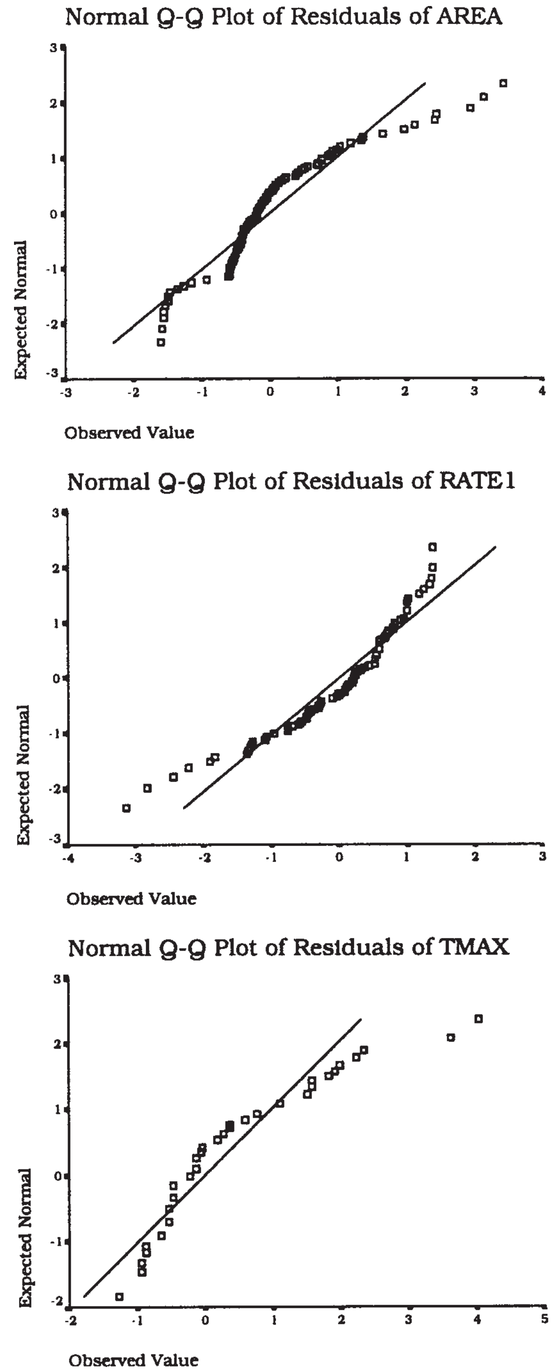


FIG. X2.3 Original and Transformed Plots

principal components, see Table X2.3 and Table X2.4. Both PC1 and the respective related variables were significant. Duncan's pairwise comparison found the caramel, carrot, and tootsie roll to have the largest T-I curves, followed by gum drops, then frankfurters with smaller curves. Finally, corn bread, rye bread, and gelatin had the smallest T-I curves. In other words, the caramel, tootsie roll, and carrot required the most work, while the corn bread, gelatin, and rye bread required the least work to complete mastication.

X2.9.1 The other two principal components did not find significant differences among the samples. However, Rate1, which was somewhat related to PC2, was significant. Rate1, the rate of increase, was highest among samples with large T-I curves, with the exception of the frankfurters. The frankfurters have a high rate of increase and a smaller curve size, suggesting that it broke down faster (smaller I_{max}) than the caramel, carrot, or gum drop.

X2.10 The first underlying factor was found to characterize

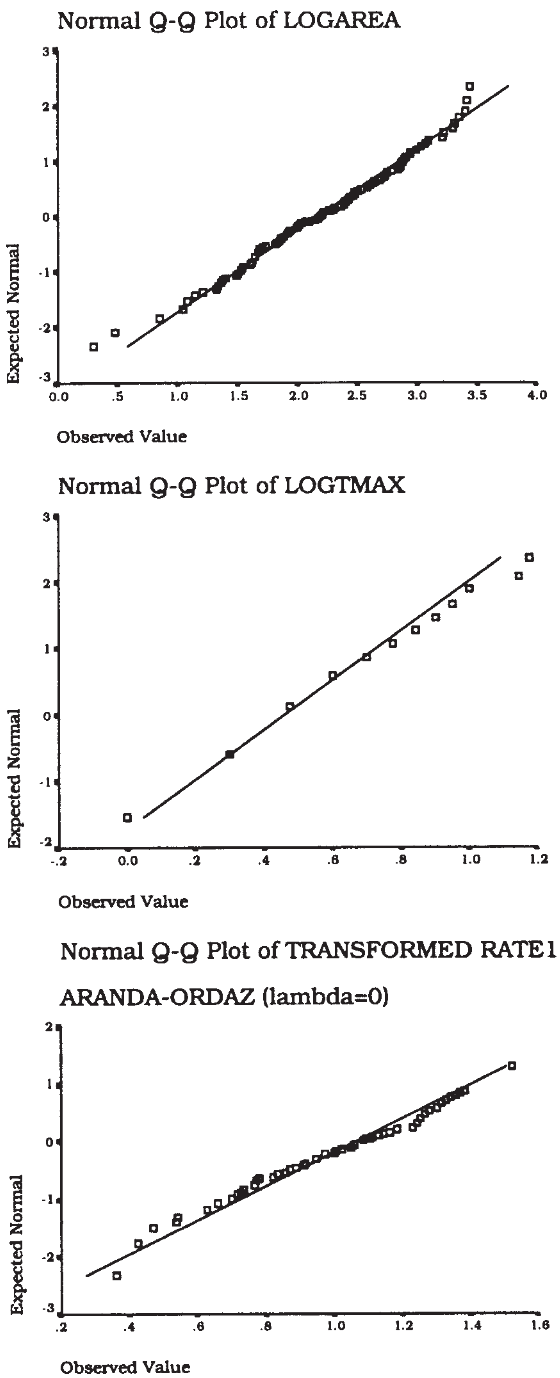


FIG. X2.4 Original and Transformed Plots

TABLE X2.1 Summary Statistics From Principal Components Analysis

PC	Communality	Eigenvalue	Variability Explained Proportion	Variability Explained Cumulative
1	1	3.85287	48.2	48.2
2	1	1.93180	24.1	72.3
3	1	1.13105	14.1	86.4
4	1	0.83346	10.4	96.9
5	1	0.12293	1.5	98.4
6	1	0.07962	1.0	99.4
7	1	0.04013	0.5	99.9
8	1	0.00814	0.1	100.0

TABLE X2.2 Standardized Principal Components Loadings (High Loadings are Shown in Boldface)

NOTE 1—Transformation for Rate1 from Aranda-Ordaz (lambda = 0).

Variable	PC1	PC2	PC3
Log_e AUC	**0.98984**	–0.07727	0.03433
I_{max}	**0.91941**	–0.23409	0.12216
$\text{Log}_e T_{max}$	0.28244	**0.91985**	0.20903
$\text{Log}_e T_{init}$	0.00095	0.64193	–0.47359
$\text{Log}_e T_{ext}$	**0.93778**	0.13256	–0.17110
Trans Rate1	0.35949	**–0.73597**	–0.36952
Log_e Area1	**0.89607**	0.10678	0.39690
Rate2	–0.36931	–0.20546	**0.72361**

the temporal aspects of the chewiness of eight foods representing sensory texture standards. It characterized the overall work required to chew these foods and was primarily associated with the size of area under the curve (AUC). Thus the attribute chewiness, or the total work or force that must be repeatedly applied to a sample to render it appropriate for swallowing is an attribute that has an inherent temporal component and is best measured by the AUC.

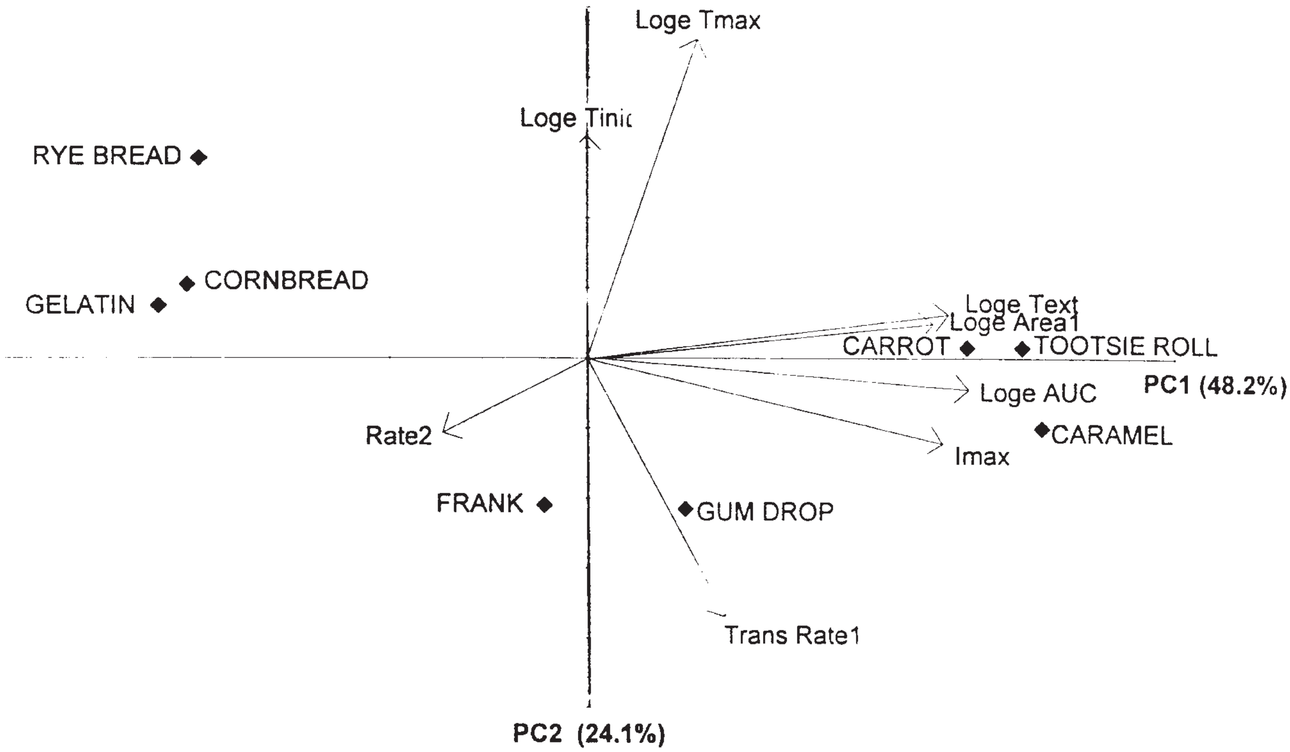


FIG. X2.5 Plot of PC1 versus PC2 for Chewiness

TABLE X2.3 Summary Results of ANOVA on Time Intensity Parameters

NOTE 1—Products sharing a common letter are not significantly different.

Product	Area	I_{max}	T_{max}	T_{init}	T_{ext}	Rate1	Area1	Rate2
5 min Frank	174.17e	26.50c	2.50	1.25	12.25b	87.18a	41.00e	70.85
Caramel	1073.75a	48.83a	3.42	1.50	37.50a	87.65a	102.00c	56.88
Carrot	658.83c	45.17a	4.75	1.83	30.33a	86.22a	120.00b	61.28
Cornbread	45.08f	9.77d	3.08	1.54	8.46b	81.91c	17.23g	66.08
Gelatin	42.14f	10.93d	3.00	1.79	7.21b	82.74bc	19.50f	63.71
Gum Drop	280.64d	33.57b	3.21	1.57	16.71b	87.22a	64.64d	67.06
Rye Bread	44.07f	10.00d	3.71	2.36	8.79b	81.54c	16.86g	67.83
Tootsie Roll	1056.15b	47.77a	4.69	1.31	34.38a	85.59ab	140.62a	61.07
F-Value	5.42	46.36	1.26	1.77	7.61	4.05	11.66	1.35
p-Value	0.001	<0.001	0.303	0.134	<0.001	0.003	<0.001	0.264

TABLE X2.4 Summary Results of ANOVA on Principal Components

NOTE 1—Products sharing a common letter are not significantly different.

Product	PC1	PC2	PC3
5 min Frank	–0.11c	–0.42	0.43
Caramel	1.16a	–0.20	–0.27
Carrot	0.97a	0.03	–0.13
Cornbread	–1.01d	0.21	–0.08
Gelatin	–1.08d	0.15	–0.27
Gum Drop	0.25b	–0.43	0.16
Rye Bread	–0.98d	0.57	–0.11
Tootsie Roll	1.11a	0.03	0.29
F-Value	69.95	1.45	0.82
p-Value	<0.001	0.224	0.576

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