Time-Intensity Methodology for Beef Tenderness Perception

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ABSTRACT

The Time-Intensity technique for measuring tenderness of bovine psoas major, longissimus dorsi, semitendinosus and shank was assessed. From the Time-Intensity curve, the Duration and area parameters (Increase and Decrease Area and Area Under the Curve) were most useful for sample separation. Using various Time-Intensity curve parameters, panelists were classified according to their perception of tenderness, with two clusters identified. A comparison of line scale results of force to chew and time to chew to the Time-Intensity results showed that comparable tenderness measurements were obtained by the two tests.

Key Words: beef, tenderness, Time-Intensity, sensory

INTRODUCTION

That texture perception constantly changes during mastication is well documented. Although techniques such as the sensory Texture Profile Analysis (TPA) can give an indication of texture characteristics as they appear during mastication, the changes occurring in such attributes are generally not recorded. A recent sensory technique which incorporates the dynamic nature of mastication is Time-Intensity sensory evaluation. The Time-Intensity approach was originally developed for use as a measurement of bitterness perception in beer and medicinal drugs (Nielson, 1957). Although researchers have alluded to the need for such a test to measure the temporal aspects of tenderness (Szczesniak, 1990; Noble et al., 1991) the majority of research completed using the sensory technique of Time-Intensity has been in flavor evaluation. Only three reports have been published using Time-Intensity as a sensory measurement of texture perception. These include viscosity measurements of ice cream (Moore and Shoemaker, 1981); oral viscosity of chocolate pudding (Pangborn and Koyasako, 1981); and hardness of gelatin cubes after one bite (Larson-Powers and Pangborn, 1978).

Tenderness is the most important attribute influencing the palatability of beef (Szczesniak and Torgeson, 1965). The use of Time-Intensity as a measurement of beef tenderness could provide a more thorough understanding of this attribute and its changes during mastication. Our objective was to establish the use of Time-Intensity as a measurement of beef tenderness perception. This technique was also compared to conventional line scale measurement of tenderness.

MATERIALS & METHODS

Sample preparation

Four bovine muscles, consisting of psoas major, longissimus dorsi, semitendinosus and shank muscles were obtained from the University of Guelph. For sample preparation, each muscle was cut into 10 cm slices and frozen until used. For testing, only the centre slice of the muscle was removed from the freezer and held at room temperature (≈23°C) for 1 hr. Each muscle was cut into 1.2 cm slices, trimmed of fat and sectioned into 1.2 cm cubes. To reduce variability, all samples were taken from the inner portion of each muscle. Individual cubes were sealed into 20 mL borosilicate sample vials and refrigerated for 3 hr until cooking. Cooking of the meat was completed in a 67.5°C circulating water bath (CARON refrigerated and heating circulating water bath, Model #2065, serial no. 2105-01) to obtain an end point of 65°C. After cooking, each 1.2 cm cube was removed from the vial and placed in a 30 mL solo cup, lidded and labeled with a random 3-digit code. Samples were placed in a polyfoam well to retain heat.

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Sensory training

Both line scale and Time-Intensity evaluations were completed by 11 trained panelists with experience in meat evaluation from the University of Guelph. These panelists received training in both line scale and Time-Intensity evaluations prior to completion of the test. Since all panelists were experienced in line scale evaluations of meat tenderness, training for the line scale involved a review of definition of the two attributes (force to chew and time to chew) to be evaluated. Force to chew was defined as perceived tenderness of the sample after three chews, while the time to chew was the time required to chew the sample from the first bite through to swallowing. The training process for the Time-Intensity tenderness test was more complex. In that study extensive training was required to ensure that panelists were comfortable with using a computer mouse to input the data while simultaneously chewing and evaluating samples. To do this panelists received training in 15 sessions, over a 3-wk. period.

During the initial stage of Time-Intensity training, panelists were presented with samples representing the expected range of tenderness of the bovine muscles to be tested and assessed the force to chew on a 10 cm line scale. In the second stage of training, the line scale test was modified to allow panelists to gain experience in simultaneous evaluation of tenderness while chewing. This was done by instructing each panelist to evaluate tenderness perception and mark responses on a 10 cm line at initial chew and every third chew until swallowing. The next stage of training involved an introduction of the CSA Time-Intensity program (Compusense Inc., Guelph, Canada) to the panelists. Panelists used a mouse to input sensory perceptions on a 60 pixel line labelled with anchors of low force to chew (left anchor) and high force to chew (right anchor). None of the panelists had used a mouse before in this capacity; therefore, extensive training was required to develop hand-eye coordination for the task. A mouse track was designed to allow for only lateral mouse movement so that any unnecessary longitudinal movements of the mouse would not affect intensity responses.

Sensory testing

During testing, each of the samples (psoas major, longissimus dorsi, semitendinosus, and shank muscles) was presented for evaluation in four replications on four separate days. The cooked samples were immediately presented to the panelists in the styrofoam wells to retain heat during evaluation which took ≈10 min for the four samples. Both Time-Intensity and line scale evaluations were completed using CSA (Findlay et al., 1986). For the line scale test panelists were asked to input the data on a 40 pixel line, representing a 10 cm unstructured line scale. The line scale testing of force to chew and time to chew was completed subsequent to the Time-Intensity evaluation on each of the four days. A 10 min break was given between the 2 tests to reduce panelist fatigue.

For Time-Intensity testing, the computer was programmed to record responses each second up to a maximum of 45 sec. Panelists were requested to place the sample with the fibres perpendicular to the back molars and upon biting down, testing was initiated by clicking the button on the mouse. Responses were continuously recorded on a scale labelled with anchors of low force to chew and high force to chew.

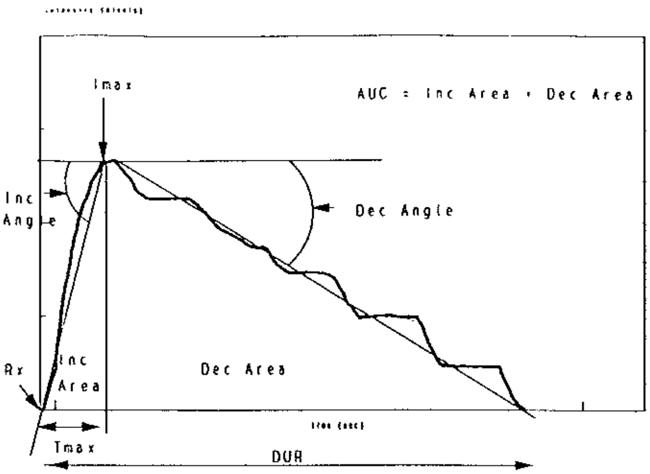

Fig. 1—Parameters and their definitions for Time-Intensity curves
Maximum intensity (Imax): the highest force to chew (in pixel) as input into the computer by each panellist
Time at maximum intensity (Tmax): time (in sec) required to reach maximum force to chew
Duration (Dur): the time (in sec) required to complete the test from first bite through to swallowing
Increase angle (Inc Angle): the angle (in degrees) of ascent from the start of the test to maximum intensity
Decrease angle (Dec Angle): the angle (in degrees) of descent from maximum intensity to the last recorded value
Decrease area (Dec Area): the area under the descending portion of the curve from Imax to the last recorded value
Area under the curve (AUC): the total area under the curve
Reaction rate (Rx): the time (in sec) at which the attributes being measured were first detected.

Table 1—Analysis of variance of force to chew and time to chew of line scale evaluations

Parameter	Source of variation	df	Anova SS	F-value	Pr>F
Force to chew (approx. cm)	Muscle	3	1059.84	147.99	0.0001
	Rep	3	33.46	4.67	0.0044
	Judge	10	56.70	2.38	0.0152
	Muscle* Rep	9	17.58	0.82	0.6006
	Muscle* Judge	30	116.54	1.65	0.0412
	Judge* Rep	30	70.96	0.99	0.4923
	Error	90	214.84		
Time to chew (approx. cm)	Muscle	3	1033.14	134.19	0.0001
	Rep	3	9.65	1.25	0.2950
	Judge	10	93.43	3.64	0.0004
	Muscle* Rep	9	21.61	0.94	0.4983
	Muscle* Judge	30	150.24	1.95	0.0083
	Judge* Rep	30	71.54	0.93	0.5766
	Error	90	230.96		

Table 2—Mean[a] values and standard deviations for line scale evaluations of force to chew[b] and time to chew[c]

Attribute	Sample			
	Psoas major	L. dorsi	Semitendinosus	Shank
Force to chew (approx. cm)				
Mean	1.9a[d]	2.3a	6.9b	7.1b
S.D.	1.56	1.82	1.61	1.85
Time to chew (approx. cm)				
Mean	2.2a	2.7a	6.8b	7.7b
S.D.	1.83	2.00	1.55	1.90

[a]n = 44
[b]samples were rated on a 40 pixel unstructured scale (0 = lower force, 10 = high force to chew)
[c]samples were evaluated on a 40 pixel unstructured scale (0 = short time, 10 = long time to chew)
[d]means not followed by the same letter are significantly different (p≤0.05)

Statistical Analysis

Intensity responses of the line scale force to chew and time to chew were obtained from the CSA line scale analysis program (Findlay et al., 1986). The results were analyzed by ANOVA and Tukey's HSD test (SAS Institute, Inc., 1991) for the determination of significant differences in tenderness perception of the four muscles.

Time-Intensity curves for each individual were plotted with time on the X-axis and intensity of the Y-axis. The Time-Intensity parameters of maximum intensity (Imax), time at maximum intensity (Tmax), reaction time (Rx), total duration (DUR), increase angle (Inc Angle), increase area (Inc Area), decrease angle (Dec Angle), decrease area (Dec Area) and area under the curve (AUC) were obtained for each curve using the Time-Intensity analysis of CSA (Findlay et al., 1986). An example of a Time-Intensity curve as well as definitions of these parameters are illustrated in Fig. 1. These parameters were analyzed by analysis of variance (ANOVA) and Tukey's HSD test (SAS Institute, Inc., 1991) to determine which parameters were effective in separating the samples.

In order to explore groupings of individual perception patterns, cluster analysis was completed on the Time-Intensity parameters using WARDS Minimum Variance Clustering Method (SAS Institute, Inc., 1991). To explore the relationship between line scale and the Time-Intensity results, Pearson Product Moment Correlation coefficients were calculated (SAS Institute, Inc., 1991).

RESULTS & DISCUSSION

Line scale results

Line scale ANOVA results for force to chew and time to chew (Table 1) were greatly affected by type of muscle, with a highly significant muscle effect observed for both attributes (F-value = 147.99 and 134.19, respectively, $p \leq 0.0001$). Tukey's results for both force to chew and time to chew (Table 2) indicate the four muscles were classified into two tenderness groupings. As expected, the psoas major and longissimus dorsi muscles were significantly more tender (less force to chew) and required less time to chew then semitendinosus and shank muscles. Tenderness perception changed over the four replications, as shown by the significant rep effect for force to chew (F-value = 4.67, $p \leq 0.0044$). This was attributed to the panel becoming more trained over the four reps. Significant judge effects (Table 1) for perceptions of both force to chew and time to chew ($p \leq 0.0152$ and $p \leq 0.0004$ respectively) were observed. This significance was considered to be inherent within the line scale test and is attributed to differences in the range of scoring and variations in the use of the scale (Arnold and Williams, 1986).

Time-intensity results

Of the nine Time-Intensity parameters evaluated, the Imax, DUR, Inc Angle, Inc Area, Dec Area and AUC differentiated between the four muscles based on tenderness perception ($p \leq 0.0001$, Table 3). No significant differences in muscle tenderness were observed using the parameters of Tmax, Rx and Dec Angle. The Rx was considered to be a reaction of the panelists to moving the mouse to maximum intensity and did not provide any information regarding the samples. Examination of the Tukey's HSD results (Table 4) revealed that the DUR and Area parameters (Inc area, Dec area and AUC) were most useful for discriminating between muscle tenderness based on significant differences obtained for the four muscles. The parameters of Imax and Inc Angle only separated the muscles into two tenderness groupings. The fact that AUC was able to separate the treatments into groups according to tenderness perception substantiates the claim by Larson-Powers and Pangborn (1978) regarding usefulness of this parameter in measuring total perception. Assessment of the tenderness groupings produced by the significant Time-Intensity parameters showed that differences existed between the shank and semitendinosus for duration of chewing as well as area parameters. The shank required the longest duration of chewing and displayed the

Table 3—ANOVA results of various parameters obtained from time intensity curve analysis

Parameter	Source of variation	df	Anova SS	F-value	Pr>F
Imax (pixel)	Muscle	3	27762.11	183.14	0.0001
	Rep	3	910.24	6.00	0.0009
	Judge	10	9751.22	8.82	0.0001
	Muscle* Rep	9	404.87	0.89	0.5374
	Muscle* Judge	30	4228.45	2.79	0.0001
	Judge* Rep	29	2339.81	1.60	0.0502
	Error	87	4396.14		
Tmax (seconds)	Muscle	3	6.695	1.74	0.1646
	Rep	3	1.321	0.34	0.7939
	Judge	10	119.73	9.34	0.0001
	Muscle* Rep	30	8.660	0.75	0.6614
	Muscle* Judge	9	109.47	2.85	0.0001
	Judge* Rep	29	47.47	1.28	0.1926
	Error	87	6.765		
Rx (seconds)	Muscle	3	0.32	1.40	0.2489
	Rep	3	0.22	0.98	0.4046
	Judge	10	4.40	5.67	0.0001
	Muscle* Judge	9	0.54	0.78	0.6336
	Muscle* Rep	30	2.31	0.99	0.4899
	Judge* Rep	29	1.87	0.06	0.7074
	Error	87	6.76		
DUR (seconds)	Muscle	3	9081.95	137.77	0.0001
	Rep	3	425.39	6.45	0.0005
	Judge	10	5500.32	25.03	0.0001
	Muscle* Rep	9	481.22	2.43	0.0162
	Muscle* Judge	30	1858.10	2.82	0.0001
	Judge* Rep	29	1009.95	1.58	0.0530
	Error	87	1911.67		
Inc Angle (degrees)	Muscle	3	312.92	13.94	0.0001
	Rep	3	32.19	1.44	0.2375
	Judge	10	678.96	9.08	0.0001
	Muscle* Rep	9	643.99	0.96	0.4799
	Muscle* Judge	30	369.86	1.65	0.0377
	Judge* Rep	29	232.59	1.07	0.3871
	Error	87	649.59		
Inc Area (pixel²)	Muscle	3	140901.22	28.99	0.0001
	Rep	3	8020.76	1.65	0.1837
	Judge	10	63176.25	3.9	0.0002
	Muscle* Rep	9	20739.38	1.42	0.1910
	Muscle* Judge	29	49687.46	1.06	0.4070
	Judge* Rep	30	191168.67	3.98	0.0001
	Error	87	140949.80		
Dec Angle (degrees)	Muscle	3	511.75	1.94	0.1295
	Rep	3	261.97	0.99	0.4006
	Judge	10	24571.72	27.91	0.0001
	Muscle* Rep	9	1586.36	2.00	0.0485
	Muscle* Judge	30	8452.11	3.23	0.0001
	Judge* Rep	29	4437.03	1.74	0.0261
	Error	87	7659.95		
Dec Area (pixel²)	Muscle	3	21963139.98	122.81	0.0001
	Rep	3	1285772.26	7.19	0.0002
	Judge	10	3980318.91	6.68	0.0001
	Muscle* Rep	9	1088573.33	2.03	0.0453
	Muscle* Judge	30	6318731.13	3.53	0.0001
	Judge* Rep	29	1461687.09	0.85	0.6887
	Error	87	5186110.73		
AUC (pixel²)	Muscle	3	25499626.12	144.71	0.0001
	Rep	3	1421594.13	8.07	0.0001
	Judge	10	4450373.11	7.58	0.0001
	Muscle* Rep	9	999113.49	1.89	0.0639
	Muscle* Judge	30	7310968.88	4.15	0.0001
	Judge* Rep	29	1551887.47	0.91	0.5997
	Error	87	519980.31		

largest AUC and Inc and Dec Areas. There were no differences in any parameter between the psoas major and longissimus dorsi muscles, however those 2 muscles were significantly more tender than the semitendinosus and shank. Representative curves for each of the 4 muscles (Fig. 2) indicated tha the shape of the curves was similar for each muscle, however, tough mucles exhibited a larger curve than more tender muscles.

Correlation coefficients (Table 5) indicated considerable relatedness between the parameters. As expected, AUC and Dec Area ($r = 0.99$, $p \leq 0.0001$) highly correlated. In addition,

Table 4—Mean[a] values and standard deviations for time-intensity parameters of tenderness

Parameter	Treatment			
	P. Major	L. dorsi	Semitendinosus	Shank
Imax (pixel)				
Mean	23.6b[b]	25.6b	49.0a	51.8a
S.D.	11.33	12.68	11.19	10.09
Tmax (seconds)				
Mean	2.5a	2.7a	2.9a	2.3a
S.D.	1.05	1.53	2.15	1.17
Reaction (seconds)				
Mean	1.0a	1.1a	1.1a	1.0a
S.D.	0.36	0.32	0.35	0.15
DUR (seconds)				
Mean	14.6c	16.6c	28.1b	31.4a
S.D.	5.12	6.13	8.44	11.38
Inc Angle (degrees)				
Mean	85.7b	84.9b	88.3a	87.7a
S.D.	3.36	5.25	1.61	2.53
Inc Area (pixel²)				
Mean	42.5c	52.3c	84.2b	119.3a
S.D.	26.18	34.34	38.7	89.28
Dec Angle (degrees)				
Mean	59.6a	57.8a	59.9a	55.8a
S.D.	18.14	17.44	13.73	17.22
Dec Area (pixel²)				
Mean	141.2c	179.1c	727.9b	973.9a
S.D.	85.36	131.15	343.28	559.57
AUC (pixel²)				
Mean	186.8c	231.4c	813.3b	1091.8a
S.D.	103.98	147.37	345.43	582.94

[a]n = 43
[b]Means not followed by the same letter are significantly different ($p \leq 0.05$)

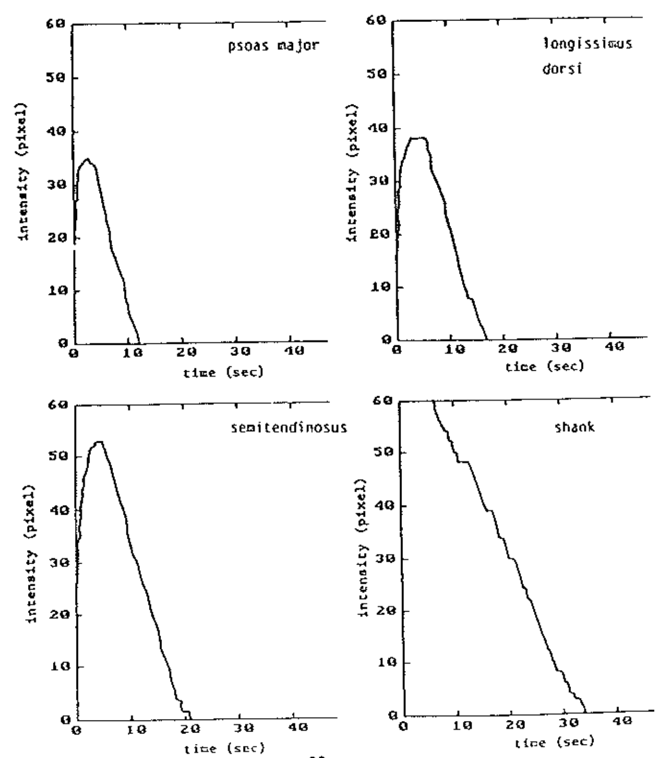

Fig. 2—Representative curves of time-intensity measurements of four bovine muscles

AUC was related to the DUR ($r = 0.86$, $p \leq 0.0001$). Imax and the area parameters of Dec Area and AUC also exhibited a significant relationship ($r = 0.81$ and 0.82 respectively,

Table 5—Correlation coefficients[a] of the Time-Intensity parameters

	Imax	Tmax	Rx	DUR	Inc Angle	Inc Area	Dec Angle	Dec Area
Tmax	−0.15[b]							
	0.3022[c]							
Rx	−0.3	0.18						
	0.0451	0.2402						
DUR	0.58	0.32	0.01					
	0.0001	0.0328	0.9481					
Inc Angle	0.64	−0.72	0.25	0.06				
	0.0001	0.0001	0.0892	0.6719				
Inc Area	0.51	0.64	−0.08	0.59	−0.05			
	0.0004	0.0001	0.5897	0.0001	0.7111			
Dec Angle	0.29	−0.33	−0.33	−0.49	0.45	−0.06		
	0.0525	0.0264	0.0267	0.0006	0.002	0.6551		
Dec Area	0.81	0.08	−0.17	0.86	0.37	0.59	−0.23	
	0.0001	0.5941	0.2683	0.0001	0.0113	0.0001	0.1281	
AUC	0.82	0.14	−0.18	0.86	0.35	0.35	−0.22	0.99
	0.0001	0.3608	0.2322	0.0001	0.0191	0.6191	0.1451	0.0001

[a]n = 172
[b]correlation coefficient
[c]prob>|R| under Ho:Rho = 0

p≤0.0001). No relationships were observed between the Inc Area and Inc Angle and the Dec Area and the Dec Angle.

ANOVA results of panelist effects revealed highly significant effects for all parameters (p≤0.0001). As well, the large standard deviations around the means (Table 2) signified a large degree of individual variability. Closer examination of F-values for the panelist effects revealed that the DUR and Dec Angle exhibited the largest judge variability (F-value = 25.03 and 27.91 respectively). The Tmax, Rx, Inc Angle and Imax also displayed large individual differences in perception (F-values = 9.34, 5.67, 9.08, 8.82 respectively). The large degree of individual variability was expected. Ott et al. (1991) found from Time-Intensity measurements of artificial sweeteners that each judge used the scale uniquely and each Time-Intensity curve was comparable to a signature of the panelist. This was further supported by other researchers (Schmitt et al., 1984; Yoshida, 1986) who found large variabilities in Time-Intensity responses to sweeteners. Noble et al., (1991) stated that the large degree of variability in perception was based on physiological differences of the individual such as dental state and jaw strength, as well as structural differences in food products. Significant muscle*judge interactions were obtained for the parameters of Imax, Tmax, DUR, Inc Angle, Dec Angle, Dec Area and AUC (p≤0.0001). Plots of these interactions revealed that panelists exhibited confusion in tenderness responses between the longissimus dorsi and psoas major muscles and between the shank and the semitendinosus muscle group.

Cluster analysis of individual scores

The variability among panelists was explored using WARDS Minimum Variance Clustering procedure (SAS Institute, Inc., 1991). The basic principle of clustering was to identify groups of individuals based on the similarity of responses to attributes measured (Godwin et al., 1978). WARDS Minimum Variance Clustering is a popular technique which joins pairs of panelists which have small total sums of squared errors (Jacobsen and Gunderson, 1986).

The parameters of Imax, Tmax, DUR, Inc Angle and Dec Angle were selected for clustering panelists on the basis of large and significant judge F-values. With these parameters, two distinct panelist perception groups were observed. The fact that only two clusters were obtained for these data was expected due to the small number of observations used for clustering and the clustering technique used, as WARD's Minimum Variance approach tends to favor clustering to the fewest clusters (Jacobsen and Gunderson, 1986).

The Time-Intensity curves in each cluster were averaged using a modification of the approach of Liu and MacFie (1991). The curves were dissected at the first point of Tmax. Initial portions of the curves were deleted and Tmax was established at time zero. The intensity of each treatment was normalized using Eq.(1). In the same manner, the time was normalized using Eq.(2).

$$I' = \frac{Imax}{Imax_i} \times I \qquad (1)$$

$$t' = \frac{(tend - tmax)}{(tend - tmax_i)} \times (t - tmax_i) + tmax \qquad (2)$$

The curve was divided into 10 equal sections and intensity was determined for each of the sections. Both time and intensity were then averaged using simple averaging to obtain an average curve for each of the four samples in each cluster.

Average curves for each cluster for the longissimus dorsi and the semitendinosus (Fig. 3) show cluster one contained six panelists, while five panelists were grouped into cluster two. Panelists in cluster one were characterized by a large force to chew (42.9 pixels) and a short time to reach maximum force to chew (1.9 sec). The perception of maximum force and the breakdown rate of samples by panelists in this cluster were rapid, as shown by a large Inc and Dec Angle (88.2°C and 66.9°C). As well, the duration of chewing (DUR) was shorter for this cluster (19.7 sec vs 26.3 sec). Cluster two panelists perceived the samples to require less force to chew (30.9 pixels) and used a longer tie to reach maximum intensity (3.3 sec). The Inc Angle was smaller (84.8°) and the breakdown rate slower, as measured by Dec Angle (48.2°).

Relationship between time-intensity and line scale results

In general, comparable measures of tenderness were obtained by Time-Intensity evaluation (Table 4) and the line scale test (Table 2), but better separation of muscles was obtained using the Time-Intensity parameters of AUC, DUR, Inc Area and Dec Area (Table 4). As expected, correlation coefficients for line scale and Time-Intensity parameters showed that AUC (r = 0.85 and 0.86), Imax (r = 0.84 and 0.82) and Dec Area (r = 0.85 and 0.86) highly correlated to both force to chew and time to chew line scale attributes.

CONCLUSIONS

THE TIME-INTENSITY sensory test was successful in separating muscles on the basis of tenderness perception. From the Time-Intensity curve, area parameters (Inc Area, Dec Area and AUC) and the time parameter of DUR were most useful for sample separation based on ability to separate shank and sem-

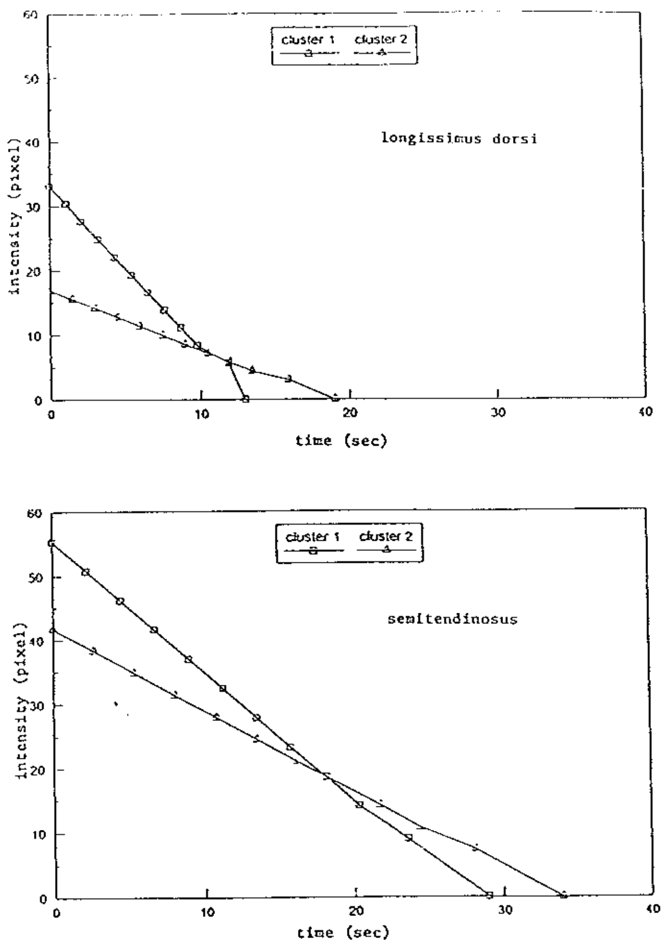

Fig. 3—Average time-intensity curves for each panelist cluster

itendinosus according to tenderness perception. Using WARD's Minimum Variance Cluster Technique, panelists were grouped into two clusters base on Time-Intensity perception patters. Cluster 1 exhibited a large Imax and short duration of chewing. In addition, perception of maximum force as well as breakdown rate of samples was rapid. Cluster 2 exhibited a long duration of chewing with a small maximum force to chew. Perception of the maximum force to chew and the breakdown rate of the samples was slow for this cluster. This was a preliminary examination into the use of Time-Intensity as a measurement of beef tenderness throughout mastication. Further research is necessary to determine if small differences in muscle tenderness can be detected using the same technique.

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