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The Relationship Between Sensory Time-intensity, Physiological Electromyography and Instrumental Texture Profile Analysis Measurements of Beef Tenderness

L. M. Duizer,[a]* E. A. Gullett[b] & C. J. Findlay[a]

[a]Compusense Inc., 150 Research Lane, Guelph, Ontario, Canada N1G 4T2
[b]Department of Food Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1

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ABSTRACT

The relationship between the perception of tenderness, chewing activity and instrumental compression was explored by time-intensity, electromyography and instrumental texture profile analysis (ITPA). Bovine m. longissimus dorsi *from five treatments were evaluated by seven individuals. Time-intensity results showed that the Decrease Area and Area Under the Curve provided the most information regarding sample differences, with the former providing the best sample discrimination. Electromyographic results of mastication rate demonstrated the number of chews required to reach maximum force to chew. The results suggest a need to re-examine the effects of early mastication vs the late mastication effects for the measurement of meat tenderness.*

INTRODUCTION

The physiological process of mastication is quite complex. Humans measure and integrate sensory perceptions on a material that undergoes continuous transformation during chewing. To reduce the expense and variability of testing with human subjects, attempts have been made to produce instruments which simulate these sensory perceptions (Szczesniak, 1986).

The instrumental measurement of meat tenderness has been studied extensively (Cover & Hostetler, 1960; Bouton & Harris, 1972*a*,*b*; McKeith *et al.*, 1985). However, instrumental testing does not simulate the complicated action of meat mastication (Szczesniak, 1986). Bouton *et al.* (1975) demonstrated a high correlation between chewiness as measured by compression and the sensory attribute of tenderness. Other researchers have shown wide ranges in correlations, from as low as $r=0.16$ to as high as $r=0.92$ for instrumental and sensory tenderness of meat (Szczesniak, 1968). This variability could, in part, be attributed to differences between the actual mastication process and the instrumental methodologies used.

*Author to whom correspondence should be addressed.

Texture profile analysis (TPA) was developed by Szczesniak *et al.* (1963) for both sensory and instrumental measurements. Both instrumental and sensory TPA moved away from a single-point system to a multi-point system where many parameters could be identified and individually quantified (Szczesniak, 1968). More recently, time-intensity evaluation has gained attention as a multi-point sensory assessment of flavour and texture. This approach differs from sensory TPA. It allows for the continuous direct measurement of one attribute throughout the mastication process, while sensory TPA measures many attributes in order of appearance throughout mastication (Civille & Liska, 1975). How time-intensity assessment of tenderness relates to instrumental TPA (ITPA) is unknown.

The objective of this research was to explore the relationship between ITPA, measured by the Ottawa Texture Measuring System (OTMS) and sensory tenderness measurements as measured over the entire mastication process by time-intensity sensory evaluation. In addition, the relationship between electromyographic masticatory information, ITPA and time-intensity tenderness measurements was assessed.

MATERIALS AND METHODS

Sample preparation

The objective of this research was to explore the relationships between time-intensity sensory evaluation and instrumental methods of TPA and electromyography. For this, a subsection of samples evaluated in another study at the University of Guelph, Ontario, Canada, were used for this research. Samples of *m. longissimus dorsi* were obtained from forage fed cattle, 12–20 months of age, slaughtered at the University of Guelph abattoir. At time of slaughter, all animals had a subcutaneous fat level of 7 mm. All subcutaneous fat measurements were taken in the last quadrant over the *m. longissimus dorsi*, measured between the interface of the 12th and 13th rib. Twenty-four hours *post mortem*, the 10th to 12th ribs from each carcass were removed and dissected into lean, fat and bone. The roast was vacuum packaged and aged for 7 days in a cooler at 1°C and then frozen at −20°C.

Five treatments, including frame size effects, ages and diet were studied in the following combinations: treatment 1: fall calf, large frame, normal diet (FLN); treatment 2: fall calf, small frame, normal diet (FSN); treatment 3: spring calf, large frame, compensatory diet (SLC); treatment 4: spring calf, large frame, normal diet (SLN); treatment 5: spring calf, small frame, compensatory diet (SSC). For sample preparation, each muscle was removed from the freezer and held at room temperature (approx. 20°C) for 1 hr. This softened the muscle enough to cut the meat into exactly 1.2 cm cubes, without any distortion in the shape of the cube. The muscles were cut into slices using a meat cutter, trimmed of fat and sectioned into cubes. The cubes were then sealed into individual 20 ml borosilicate sample vials and refrigerated until an internal temperature of 2–4°C was reached. Upon removal from the refrigerator, the samples were cooked for 20 min in a 67.5°C circulating water bath (CARON, Model No. 2065) to obtain the end-point temperature of 65°C. Three sets of cubes were prepared for testing. One set was placed in 30 ml solo cups, lidded and labelled with three digit codes and presented to the panellists for sensory time-intensity analysis. The second set was presented to the panellists for measurement of masticatory muscle movement by electromyography (EMG). The last set was used for ITPA measurement.

Sensory time-intensity analysis

Seven panellists, experienced in time-intensity analysis of tenderness were recruited from a pool of experienced panellists from the University of Guelph. All training and testing was

completed using the Computerized Time-Intensity program (CSA_{TPA}) (Compusense Inc., Guelph, ON). During training, the panellists were presented with samples representing the expected range of tenderness of the muscles in the actual test.

A completely randomized design was chosen for this study, with samples from the five treatments randomly presented for evaluation. The computer was programmed to record responses every second for 70 s. This allowed time for the panellist to record responses from the first bite through to the swallowing of the sample. The panellist initiated recording upon biting down on the sample. Responses were continuously recorded on a scale labelled with anchors of low force to chew (left) and high force to chew (right). 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.

Electromyographic testing

A physiograph (Narco Biosystems, Model 6B) was used for recording masticatory activity. Individual mastication responses were collected every 0.06 s from the physiograph using a personal computer with DATACAN software (Sable Systems).

Two surface electrodes were placed 1 cm apart on the masseter muscle for each individual. This muscle is responsible for closing the mouth during chewing (Boyar & Kilcast, 1986). Panellists placed the samples between the back molars on the dominant chewing side of the mouth. After the establishment of a baseline for each individual, chewing commenced with the sample remaining on one side of the mouth throughout mastication. All measurements of the masseter muscle movement were recorded over the entire chewing process for each sample.

Instrumental texture profile analysis (TPA)

Compression testing was done using an Ottawa Texture Measurement System (OTMS) (Model No. D1804). Data were collected using the software developed for the Apple IIe computer by the Engineering and Statistical Research Institute, Ottawa, Canada (ESRI, 1987). The cooked samples were cooled to room temperature (20°C) and placed between flat parallel plates and subjected to a two cycle compression. Samples were deformed to 70% of the original height using a crosshead speed of 8.5 cm/min. Three replications were completed for each treatment.

Statistical analysis

Time-intensity curves were plotted with time (s) on the x-axis and intensity (in pixels) on the y-axis. Using CSA_{TPA} curve analysis, the parameters of maximum intensity (*IMAX*), time at maximum intensity (*TMAX*), reaction rate (*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. An example of a time-intensity curve and definitions of these parameters have previously been published; Duizer *et al.*, 1993). 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 differentiating between the samples.

From the electromyographic curves, the total time to chew (calculated by subtracting the finish time from start time) and the number of chew cycles were determined. Using these parameters, the mastication rate was calculated as chews per second. Each of these parameters was analyzed by ANOVA and Tukey's HSD test.

Instrumental TPA force–time curves were analyzed using ESRI software (ESRI, 1987). The TPA attributes of first and second compression hardness, fracturability, cohesiveness, springiness, chewiness and adhesiveness were reported from the curves. These attributes were analyzed by ANOVA and Tukey's HSD test to determine the presence of significant differences between the treatments. Pearson Product Moment correlation coefficients were calculated between individual parameters (SAS Institute Inc., 1991), to examine the presence of a relationship between time-intensity and TPA results.

RESULTS AND DISCUSSION

Time-intensity sensory evaluation

From the ANOVA results of the time-intensity parameters, the *AUC*, *IMAX*, *DUR* and *DEC AREA* were found to be useful parameters for determining differences in tenderness between the treatments (F-values $=4.87$, 3.48, 3.25 and 5.54, respectively, $p \leqslant 0.05$). No differences ($p > 0.05$) in treatment tenderness were obtained for the parameters of *TMAX*, *INC ANGLE*, *DEC ANGLE* and *INC AREA*.

Tukey's HSD test showed the *DEC AREA* to be the most effective in separating the samples on the basis of tenderness as treatments 1 (FLN), 2 (FSN) and 3 (SLC) were observed to be significantly more tender than treatment 4 (SLN) (Table 1). The *AUC* followed this parameter in ability to differentiate between treatments, with two treatments having lower ($p \leqslant 0.05$) total areas than that of treatment 4 (SLN) (Table 1). Both *IMAX* and *DUR* followed the area parameters in treatment separation with only one treatment observed to be more tender than treatment 4 (SLN). This was exhibited by a smaller maximum force to chew (*IMAX* = 29.9 pixels) and a shorter time to chew (*DUR* = 14.4 s) for treatment 1 (FLN) than treatment 4 (SLN) (*IMAX* = 41.2 pixels, *DUR* = 19.5 s). These results indicate that age (spring calves being older) combined with a large frame and normal diet resulted in a decrease in tenderness and that the compensatory diet provided more benefit to the large frame animals in increasing tenderness. The results also show that better separation was obtained for the time-intensity parameters incorporating the effects of the late stages of the mastication process.

A large degree of judge individuality was observed with significant ($p \leqslant 0.05$) judge effects noted for the parameters of *IMAX* (F-value = 6.23), *TMAX* (F-value = 7.46), *INC ANGLE* (F-value = 6.99), *DEC ANGLE* (F-value = 26.40) and the *DUR* (F-value = 4.23). This individuality of judges was not observed for the area parameters ($p > 0.05$), which probably contributed to the area parameters better separating the samples for tenderness.

Electromyographic results

ANOVA and Tukey's HSD results for the EMG parameters of the number of chews, time to chew, and mastication rate are shown in Tables 2 and 3. Treatments differed ($p \leqslant 0.05$) for both the number of chews and time to chew parameters ($p \leqslant 0.01$ and 0.05, respectively). However, the mastication rate did not differ significantly between the five treatments suggesting that panellists' rate of chewing was not influenced by tenderness.

Individual mastication rates have been observed to influence the rate of compression in the mouth and also to have an impact on the perception of tenderness (Bourne, 1977). One of the major difficulties in determining human compression rates is the large variability in masticatory patterns as observed in this study. EMG results for the mastication rate show individual chewing rates ranging from 2.2 to 1.5 chews/s.

TABLE 1
Mean[a] Values and Tukey's HSD Ratings for Time-intensity Parameters

Parameter	*Treatment*				
	FLN	*FSN*	*SLC*	*SLN*	*SSC*
IMAX (pixel)					
Mean	29.9b	33.3ab	33.1ab	41.2a	37.0ab
S.D.	11.42	10.21	10.93	13.59	13.36
TMAX (s)					
Mean	2.3a	2.2a	2.0a	2.0a	2.4a
S.D.	1.02	1.67	0.83	1.00	1.28
DUR (s)					
Mean	14.4b	15.8ab	15.6ab	19.5a	18.2ab
S.D.	5.06	4.87	4.64	7.11	5.73
INC ANGLE (degrees)					
Mean	86.5a	87.9a	87.9a	88.1a	87.4a
S.D.	3.45	1.83	2.07	2.50	2.62
INC AREA (pixel^2)					
Mean	53.4a	76.0a	52.0a	65.7a	72.7a
S.D.	18.80	91.14	17.22	27.91	41.15
DEC ANGLE (degrees)					
Mean	61.3a	63.1a	60.5a	62.2a	61.2a
S.D.	17.15	11.34	17.08	13.34	12.58
DEC AREA (pixel^2)					
Mean	176.4b	265.6b	241.8b	432.9a	341.6ab
S.D.	134.29	157.90	132.38	274.24	200.27
AUC (pixel^2)					
Mean	252.1b	321.0ab	296.3b	498.6a	414.4ab
S.D.	152.42	170.42	129.95	284.20	223.60

[a] $n=21$.
FLN, fall calf, large frame, normal diet; FSN, fall calf, small frame, normal diet; SLC, spring calf, large frame, compensatory diet; SLN, spring calf, large frame, normal diet; SSC, spring calf, small frame, compensatory diet. Means not followed by the same letter are significantly different ($p \leq 0.05$).

The use of EMG as a measure of masticatory activity was not fully explored in this study. The original intent of the EMG research was to examine masticatory patterns through a collection of masseter muscle electrical potentials. Owing to a limitation in the software used, the number of sampling points collected was not sufficient for this observation. Further research on EMG measurements using a more accurate data collection system and an updated physiograph is required to determine masticatory muscle movements.

Boyar & Kilcast (1986) stated that the most important information regarding tenderness of the sample was provided upon the first bite. To explore the validity of this statement, the mastication rates of each individual were used to determine the number of chews at which *IMAX* was perceived for the time-intensity data. For this calculation, the

TMAX was multiplied by the mastication rate and subtracted from the reaction rate. This parameter was labelled *Cmax* (the number of chews to reach maximum intensity). The number of chews to reach maximum intensity (*Cmax*) varied among the panellists from 1 to 4 chews. This provides evidence that more than just the first bite is required to measure tenderness perception.

TABLE 2
ANOVA Results of EMG Parameters

Parameter	*Source*	*df*	*ANOVA SS*	*F-value*	*Pr > F*
Number of chews					
	Treatment	4	721.80	3.2	0.0173
	Judge	6	2507.31	7.4	0.0001
	Treatment×Judge	24	914.59	0.6	0.8528
	Error	70	3915.33		
Time to chew (s)					
	Treatment	4	191.94	2.3	0.0596
	Judge	6	605.89	5.0	0.0003
	Treatment×Judge	24	282.56	0.5	0.929
	Error	70	1410.06		
Mastication rate (chews/s)					
	Treatment	4	0.03	0.5	0.7273
	Judge	6	4.49	40.3	0.0001
	Treatment×Judge	24	0.35	0.8	0.7185
	Error	70	1.29		

TABLE 3
Mean[a] Values and Tukey's HSD Ratings for EMG Parameters

Parameter	*Treatment*				
	FLN	*FSN*	*SLC*	*SLN*	*SSC*
Number of chews					
Mean	26.3b	31.0ab	28.4ab	28.8ab	34.0a
S.D.	6.73	8.60	7.64	10.63	8.71
Time to chew (s)					
Mean	15.2b	17.8ab	16.6ab	17.0ab	19.3a
S.D.	3.62	4.83	4.48	6.30	4.29
Mastication rate (chews/s)					
Mean	1.7a	1.7a	1.7a	1.7a	3.1a
S.D.	0.21	0.20	0.24	0.27	6.39

[a] $n = 21$.
FLN, fall calf, large frame, normal diet; FSN, fall calf, small frame, normal diet; SLC, spring calf, large frame, compensatory diet; SLN, spring calf, large frame, normal diet; SSC, spring calf, small frame, compensatory diet. Means not followed by the same letter are significantly different ($p \leq 0.05$).

TABLE 4
Mean[a] Values and Tukey's HSD Results for Instrumental TPA data

Parameter	*Treatment*				
	FLN	*FSN*	*SLC*	*SLN*	*SSC*
Hardness - first bite (N)					
Mean	72.8ab	81.3a	62.1b	80.1a	75.0ab
S.D.	12.85	8.66	2.85	10.53	13.86
Hardness - second bite (N)					
Mean	59.7ab	67.7a	51.5b	64.5ab	63.7ab
S.D.	9.35	7.07	3.80	12.03	12.67
Fracturability (N)					
Mean	29.0a	29.4a	25.3a	27.8a	29.1a
S.D.	5.07	1.73	1.74	3.55	4.30
Cohesiveness					
Mean	0.5a	0.6a	0.6a	0.6a	0.6a
S.D.	0.06	0.02	0.06	0.02	0.03
Springiness (mm)					
Mean	3.8a	4.0a	5.0a	4.1a	4.1a
S.D.	0.48	0.55	3.09	0.59	0.47
Chewiness (J)					
Mean	163.2a	205.9a	186.4a	210.0a	190.6a
S.D.	25.67	39.65	108.09	38.23	41.80
Adhesiveness (-10^3 J)					
Mean	4.4a	3.8a	3.2a	5.4a	2.8a
S.D.	2.80	2.18	0.81	5.94	0.61

[a]$n=21$.
For abbreviations, see Table 1.

Texture profile analysis (ITPA)

From the OTMS ANOVA results, the first and second compression hardness (F-value = 3.84 and 3.38, respectively) differed between the treatments ($p \leq 0.05$). The parameters fracturability, cohesiveness and springiness showed no difference ($p > 0.05$) between treatments.

Comparison of ITPA results with time-intensity results (Tables 4 and 1) indicate some differences in results and suggest ITPA to be less sensitive at picking up differences. Treatment 5 (SSC) was not significantly different from other treatments by either method. However, time-intensity results indicated that treatment 1 (FLN) was significantly more tender than treatment 3 (SLC) but not by ITPA where treatment 1 (FLN) was not significantly different from any other treatment. This suggests that time-intensity parameters reflecting late mastication were better at picking up age differences than ITPA which concentrated on early mastication.

Correlation coefficients for the ITPA and time-intensity results are found in Table 5. Surprisingly, first and second bite hardness did not correlate with *IMAX* but were related to the *DEC ANGLE* and the *INC AREA* parameters, both of which are influenced by *IMAX*. The *DEC ANGLE* was significantly correlated to both first and second bite

TABLE 5
Correlation Coefficients for Time-intensity and TPA parameters

TPA Parameters	*Time-intensity parameters*							
	IMAX	*TMAX*	*DUR*	*DEC ANGLE*	*INC ANGLE*	*INC AREA*	*DEC AREA*	*AUC*
1st bite hardness	0.42[a]	0.26	0.44	0.89	0.14	0.78	0.48	0.49
	0.47[b]	0.66	0.45	0.04	0.81	0.11	0.41	0.39
2nd bite hardness	0.37	0.40	0.41	0.86	0.11	0.87	0.43	0.45
	0.53	0.49	0.49	0.06	0.85	0.05	0.46	0.44
Fracturability	–0.05	0.78	0.03	0.60	–0.41	0.64	0.005	0.05
	0.92	0.11	0.95	0.27	0.48	0.24	0.99	0.92
Cohesiveness	0.83	–0.34	0.78	0.69	0.79	0.70	0.86	0.82
	0.07	0.56	0.11	0.19	0.11	0.18	0.06	0.08
Chewiness	0.75	–0.42	0.70	0.63	0.90	0.68	0.78	0.43
	0.13	0.47	0.18	0.25	0.03	0.2	0.11	0.46
Adhesiveness	0.34	–0.42	0.26	0.44	0.10	–0.10	0.34	0.35
	0.56	0.47	0.66	0.45	0.86	0.86	0.57	0.55

[a]Correlation coefficient.
[b] $pr > R$ under $Ho = 0/n = 5$.

hardness ($r = 0.84$ and 0.86, respectively) while *INC AREA* and the second compression hardness exhibited a high correlation ($r = 0.87$).

The *DEC AREA* displayed a significantly large correlation coefficient with the TPA parameter of cohesiveness ($r = 0.86$), suggesting that the larger the decrease in area, the more cohesive the sample. This relationship, combined with the fact that the treatments did not differ ($p > 0.05$) in cohesiveness provides evidence that more than first and second compression was necessary for instrumental texture measurements. It also indicates that instrumental TPA measurements are not as sensitive to differences in tenderness as sensory measures. Instrumental measurements evaluate only first and second compression hardness, while maximum intensity was observed to occur anywhere between the first and the fourth bite. Other reasons for the low correlation between *AUC*, *IMAX* and first bite hardness could be due to the difference in deformation rates between human subjects and instruments (Voisey, 1975). Generally, instrumental tests are performed at much lower deformation rates than are present in the human mouth (Shama & Sherman, 1973) and compression rates are selected arbitrarily in response to the limitations of the instrument (Voisey, 1975). In later research, Voisey & Larmond (1977) demonstrated that an increase in the shear rate, to approximate human compression rates did not provide significantly different tenderness values than those obtained at lower compression rates.

CONCLUSIONS

Time-intensity sensory evaluation was used to explore temporal changes in tenderness over the chewing process. From the time-intensity parameters, the *DEC AREA* and *AUC* provided the most information about tenderness differences between the treatments. These two time-intensity parameters (*AUC* and *DEC AREA)* include an energy factor (time x force) that the *IMAX* and *DUR* do not (one being force and the other being time). Time-intensity angle parameters contain a high judge effect, probably decreasing their effectiveness in separating treatments.

Although Boyar & Kilcast (1986) stated that the first bite provided all important information for tenderness perception of food, the recalculation of *TMAX* to produce *Cmax* provided evidence that the intensity perception of meat is not necessarily a first bite event, but dependent on individual mastication rates. With regard to the relationship between sensory time-intensity and ITPA measures, instrumental TPA measurements are not as sensitive to differences in meat tenderness as sensory time-intensity measures. The maximum intensity perception occurred anywhere from the first to the fourth bite while instrumental measures evaluated only first and second compression hardness.

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REFERENCES

Bourne, M. C. (1977). *J. Texture Stud.*, **8**, 219.
Bouton, P. E., Ford, A. L., Harris, P. V. & Ratcliff, D. (1975). *J. Texture Stud.*, **6**, 315.
Bouton, P. E. & Harris, P. V. (1972*a*). *J. Food Sci.*, **37**, 140.
Bouton, P. E. & Harris, P. V. (1972*b*). *J. Food Sci.*, **37**, 218.

Boyar, M. M. & Kilcast, D. (1986). *J. Texture Stud.*, **17**, 221.
Civille, G. V. & Liska, I. H. (1975). *J. Texture Stud.*, **6**, 19.
Cover, S. & Hostetler, R. L. (1960). Bull. No. 947. Texas Agr. Expt. Sta.
Duizer, L. M. Gullett, E. A. & Findlay, C. J. (1993). *J. Food Sci.*, **58**(5), 943.
ESRI (1987). *Manual for the Apple II Computer Based Texture Data Acquisition and Analysis System.* Agriculture Canada.
McKeith, F. K., DeVol, D. L., Miles, R. S., Bechtel, P. J. & Carr, T. R. (1985). *J. Food Sci.*, **50**, 869.
SAS Institute Inc. (1991). *SAS User's Guide: Statistics, Version 6 Edition.* SAS Institute, Cary, North Carolina.
Shama, F. & Sherman, P. (1973). *J. Texture Stud.*, **4**, 344.
Szczesniak, A. S. (1968). *Food Technol.*, **22**, 979.
Szczesniak, A. S. (1986). *Proc. 39th Annual Reciprocal Meat Conference of the AMSA*, pp. 86–96.
Szczesniak, A. S., Brandt, M. A. & Friedman, H. (1963). *J. Food Sci.*, **28**, 397.
Voisey, P. W. (1975). *J. Texture Stud.*, **6**, 253.
Voisey, P. W. & Larmond, E. (1977). *J. Can. Inst. Food Sci. Technol.*, **10**(4), 307.