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Association between Electromyography (EMG) variables during Mastication by Human Subjects and food texture perceptions: A study on different snacks (*gajaks,* biscuits and chocolates)

Pratiksha, Navdeep Singh Sodhi,* Bhavnita Dhillon, Tanbeer Kaur
Department of Food Science and Technology,
Guru Nanak Dev University, Amritsar 143 005, Punjab, India.
*Corresponding Author: Tel.: +91-95014-73321; +91-183-2258802 Extn: 3381
E-mail: navdeep.food@gndu.ac.in (Dr. N.S. Sodhi)

ABSTRACT
The present study was conducted with an aim to correlate electromyography variables with the sensory attributes of different snacks (gajaks, biscuits and chocolates). A comparison of absolute and relative values of acquired EMG variables showed that the relative EMG mastication parameters eliminate subject variance and can effectively distinguish different textured food products. The reproducibility of the EMG variables was investigated by correlating two different recordings of human subjects in a session for different textured foods. The statistically significant (p<0.05) correlation coefficients for two different recordings of various foods indicated highly reproducible chewing behaviour within a session for human subjects. EMG variables were grouped into six representative variables by performing cluster analysis. The principal component analysis of these six representative variables resulted in two independent components which could explain 88.7% of cumulative proportion of variance. The scores of first principal component correlated significantly with sensory hardness and chewiness, while scores of second component correlated with sensory adhesiveness.
Key words: electromyography, mastication, sensory evaluation, food texture.

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INTRODUCTION

Texture is an important aspect of food quality. It is a sensory property as well as a multi-parameter attribute, which is derived from food structure and is detected by several senses. The sense of vision, hearing, touch and kinaesthetic can be used to derive the sensory and functional attributes of the properties of food. Compressive, tensile and shearing forces break down food into smaller particles during the mastication process [14]. The biting pattern and the biting length are highly influenced by the mechanical strength and mechanical nature of the food [3]. During mastication, there is a gradual change in size, texture and moisture value of food in the mouth [12]. Mastication not only breaks down food into smaller particles for swallowing and digestion but forms the basis of texture evaluation by providing sensory feedback [2]. The study of human mastication process during chewing of different foods can be done with the help electromyography, a non-invasive technique, which measures muscular electrical activity [10].

The whole chewing process can be studied to provide information about food texture by using EMG as a recent technique [4]. EMG is a harmless technique used to register muscular activity with the help of surface electrodes. During oral processing, effect of food texture on the messeter muscles, the jaw-closing muscles, can be studied by using EMG [8]. Signals generated by the muscular activity are captured by placing bipolar electrodes on the messeter muscles. A neutral electrode is placed on the wrist or forehead. When the subject grits his/her teeth, the muscles are identified by touching them. Conductance is improved by cleaning the skin with alcohol and applying a conducting gel before putting electrodes to its place. The EMG signals supply graphic information when transformed and registered on a personal computer. The EMG signals are usually registered from the time of first bite to just before the first swallow. The EMG signals can be grouped based on voltage, time and voltage/time parameters to explain food texture [4].

Each individual will have a different length of time and number of chewing cycles for different foods which may be attributed to the rheology of food [3]. During early stage of mastication, original textural differences between foods are more significant but tend to decrease during intra-oral transformation [7]. EMG evaluates the chew effectiveness by measuring the work exerted by the subject on the food product before swallowing it and is determined by the parameters such as chew number, chew work and chew time [1]. The individual results produced by EMG are stable over a period of time and can be reproduced but varies from subject to subject. In order to maintain the subject's physiological conditions, the time of the day for carrying out experiments should always be same in order because any variation in these may alter the EMG response [4]. The studies have shown that the EMG responses vary significantly with food composition, size, geometry and rheology. EMG allows better assessment of sensory characteristics then mechanical measurements. It gives the real time information of the whole chewing process to characterize food texture. Thus offers a way of monitoring chewing patterns and highlights textural differences in foods [5]. Hence, the technique needs to be standardized for its applicability in designing of food products.

The present study was conducted with the objective to acquire the EMG signals for different textured foods and to relate EMG parameters with food texture perceptions.

MATERIALS AND METHODS

Subjects

The conduct of present study was approved by the Ethical Committee of Guru Nanak Dev University, Amritsar. In this investigation, EMG studies were conducted on ten volunteer subjects (five males and five females, aged 18 – 26 years) who were free from any functional mastication problems, and required no dental treatments (Figure 1). Informed consent was given by all the subjects prior to the EMG sessions. Subjects were asked to masticate and swallow samples in a habitual way to avoid imposed eating [10]. The recording sessions lasted for about half an hour.

EMG

EMG activities of both sides of masseter muscles, the jaw-closing muscles, were measured using EMG [9-10, 13], while the subjects ate one mouthful (6 g) of six different textured food products (hard biscuit, soft biscuit, *mungfali gajak, til gajak,* crunch chocolate and plain chocolate). The signals were obtained from EMG using bipolar surface electrodes (Figure 2), filtered (10 – 500 Hz) then amplified 2,000 times and saved on a PC using MP-150 system (Acknowledge ver. 4.4.2, Biopac Systems Inc.) at 1,000 Hz.

Sensory evaluation

Sensory evaluation was carried out for 6 samples by 10 subjects using Hedonic Scale. They were asked to evaluate the samples on the basis of sensory parameters i.e. hardness, cohesiveness, fracturability, chewiness, gumminess, and adhesiveness and give marks accordingly on the Sensory Card on the basis of 9 points where 9 represents highest perceived sensation and 1 represents least perceived sensation.

Data analysis

Two-way analysis of variance, cluster analysis and principal component analysis of acquired EMG variables were performed with Minitab Statistical Software (Minitab Inc., USA).

RESULTS AND DISCUSSION

Comparison of absolute and relative values of EMG variables

The acquired absolute EMG variables (chew number, total cycle time, total burst duration, total muscle activity, total inter burst duration, burst duration per chew, muscle activity per chew, amplitude per chew, inter burst duration per chew, cycle time per chew, early burst duration, early muscle activity, early amplitude, early inter burst duration, early cycle time, middle burst duration, middle muscle activity, middle amplitude, middle inter burst duration, middle cycle time, late burst duration, late muscle activity, late amplitude, late inter burst duration and late cycle time) were subjected to analysis of variance for different food samples. Out of these fifteen masticatory parameters (total burst duration, total muscle activity, total inter burst duration, burst duration per chew, cycle time per chew, muscle activity per chew, amplitude per chew, early burst duration, early muscle activity, early amplitude, early inter burst duration, middle burst duration, middle amplitude, late inter burst duration and late cycle time) could statistically (p<0.05) distinguish among different foods investigated in the present study. These fifteen masticatory parameters were used for conducing two-way analysis of variance. The analysis of variance indicated more variation in subjects as compared to textural variations in the food samples (Table 1). Similar results have been reported earlier [7, 8]. Relative values of EMG variables are often used in kinesiology [8]. Accordingly, the relative mastication parameters (ratio to mean value of 6 foods × duplicates) within each subject were served for statistical analysis rather than using absolute values. The analysis of variance conducted on relative mastication parameters indicated significant differences among different food samples (Table 2). The results indicated that the relative EMG mastication parameters eliminate subject variance and can effectively distinguish different textured food products.

TABLE 1. EMG masticatory parameters (absolute values) for various food samples showing subject factor variation.

Food samples	Hard biscuit	Soft biscuit	*Mungfali gajak*	*Til gajak*	Crunch chocolate	Plain chocolate	F-value subjects	F-value foods
			Entire mastication parameters					
Total burst duration (s)	8.39	8.64	10.4	10.38	10.18	10.01	4.38	1.09
Total muscle activity (mV·s)	0.65	0.67	0.91	0.80	0.89	0.81	103.6	9.39
Total inter burst duration (s)	14.50	13.99	14.55	13.11	15.88	15.94	28.82	4.36
			Per chew mastication parameters					
Burst duration (s)	0.28	0.29	0.31	0.31	0.31	0.29	21.64	3.29
Cycle time (s)	0.78	0.72	0.74	0.77	0.81	0.81	11.60	3.16
Muscle activity (mV·s)	0.02	0.02	0.03	0.03	0.04	0.06	1.32	1.95
Amplitude (mV)	0.99	0.98	1.11	1.08	1.07	1.04	206.10	4.23
			Early stage mastication parameter					
Burst duration (s)	1.48	1.57	1.88	1.77	1.91	1.92	5.53	5.23
Muscle activity (mV·s)	0.11	0.11	0.14	0.15	0.17	0.16	32.43	12.74
Amplitude (mV)	4.74	4.79	5.19	5.18	5.62	5.45	45.27	1.75
Inter burst duration (s)	2.26	2.23	1.98	1.96	2.02	1.92	16.71	2.99
			Middle stage mastication parameters					
Burst duration (s)	1.34	1.38	1.53	1.52	1.51	1.503	3.59	0.91
Amplitude (mV)	5.47	5.26	6.01	5.62	5.26	5.40	62.90	1.29
			Late stage mastication parameters					
Inter burst duration (s)	2.88	2.79	2.69	2.82	3.31	3.54	20.75	6.91
Cycle time (s)	4.12	4.07	4.03	4.12	4.55	4.72	19.39	4.18

TABLE 2. EMG masticatory parameters (relative values) for various food samples showing food factor variation.

Food samples	Hard biscuit	Soft biscuit	*Mungfali gajak*	*Til gajak*	Crunch chocolate	Plain chocolate	F-value	p-value
Entire mastication parameters								
Total burst duration (s)	0.86	0.89	1.08	1.04	1.08	1.04	1.63	0.17
Total muscle activity (mV·s)	0.79	0.82	1.16	1.01	1.17	1.04	10.29	0.00
Per chew mastication parameters								
Burst duration (s)	0.95	0.96	1.03	1.05	1.05	0.95	2.86	0.02
Cycle time (s)	1.01	0.93	0.96	1.00	1.05	1.05	3.46	0.01
Muscle activity (mV·s)	0.74	0.74	0.89	0.93	1.19	1.50	2.04	0.09
Amplitude (mV)	0.95	0.92	1.06	1.04	1.02	1.00	5.04	0.00
Early stage mastication parameter								
Burst duration (s)	0.85	0.89	1.06	1.01	1.09	1.09	5.58	0.00
Muscle activity (mV·s)	0.78	0.75	1.01	1.06	1.22	1.16	12.87	0.00
Amplitude (mV)	0.89	0.90	1.03	1.01	1.09	1.08	2.49	0.05
Inter burst duration (s)	1.08	1.08	0.96	0.95	0.98	0.94	2.81	0.03
Middle stage mastication parameters								
Burst duration (s)	0.91	0.94	1.04	1.04	1.02	1.03	0.88	0.50
Amplitude (mV)	0.98	0.94	1.08	1.03	0.96	0.99	1.30	0.28
Late stage mastication parameters								
Inter burst duration (s)	0.96	0.93	0.90	0.94	1.11	1.17	7.11	0.00
Cycle time (s)	0.97	0.96	0.95	0.96	1.06	1.10	3.54	0.01

Reproducibility of masseter muscle activities

The reproducibility of the EMG variables for entire duration (total burst duration, total muscle activity and total inter burst duration), per chew mastication parameters (burst duration, cycle time, muscle activity and amplitude), early stage mastication parameters (burst duration, muscle activity, amplitude and inter burst duration), middle stage mastication parameters (burst duration and amplitude) and late stage mastication parameters (inter burst duration and cycle time) was investigated by correlating two different recordings in a session of human subjects for different textured foods. Correlation coefficients were found to be statistically significant ($p<0.05$) for two different recordings of various foods (Tables 3-7). There was a high degree of similarity between the two different recordings of masticatory parameters of the same subject during a session indicating highly reproducible chewing behaviour. Thus EMG masticatory parameters can be used to study differences in texture among various food products. A representative dendrogram generated by cluster analysis for *mungfali gajak* depicted the similarity in subjects' chewing behaviour during two different recordings in an EMG session (Figure 3). It was observed that the same subject's recordings were clustered more closely with each other than those of other subjects. Each individual will have different chewing response to different textures but intra-individual EMG data is reproducible [15]. Karkazis and Kossioni [6] also showed in their study that EMG activity is highly reproducible during mastication and is explained by low variation within session. Thus it can be inferred that chewing behaviour is reproducible within a session for human subjects and can be used for investigating textural differences among various foodstuffs.

Principal Component Analysis

A principal component analysis of EMG variables was conducted to pick smaller number of independent variables to explain the variability in mastication behaviour of different human subjects. However, cluster analysis was carried out before conducting principal component analysis to reduce the number of masticatory parameters. Kohyama *et al.* [8] in their study also proved that cluster analysis followed by principal component analysis is useful for classifying human masticatory parameters to a smaller number of independent factors. The masticatory parameters were grouped into six clusters by conducting cluster analysis with the help of dendrogram (Figure 4). From these clusters, six variables viz. amplitude per chew, burst duration per chew, late inter burst duration, early muscle activity, early inter burst duration, and middle amplitude representing each cluster were selected for principal component analysis.

TABLE 3. Correlation coefficients (r) of two different recordings in an EMG session for entire mastication parameters.

Food	Parameters	r
Hard biscuit	Total burst duration (s)	0.82**
	Total muscle activity (mV·s)	0.96**
	Total inter burst duration (s)	0.91**
Soft biscuit	Total burst duration (s)	0.80**
	Total muscle activity (mV·s)	0.96**
	Total inter burst duration (s)	0.79**
Mungfali gajak	Total burst duration (s)	0.85**
	Total muscle activity (mV·s)	0.95**
	Total inter burst duration (s)	0.91**
Til gajak	Total burst duration (s)	0.87**
	Total muscle activity (mV·s)	0.96**
	Total inter burst duration (s)	0.80**
Crunch chocolate	Total burst duration (s)	0.79**
	Total muscle activity (mV·s)	0.95**
	Total inter burst duration (s)	0.67*
Plain chocolate	Total burst duration (s)	0.87**
	Total muscle activity (mV·s)	0.87**
	Total inter burst duration (s)	0.89**

*$p<0.05$; **$p<0.01$

TABLE 4. Correlation coefficients (r) of two different recordings in an EMG session for mastication parameters per chew.

Food	Parameters	r
Hard biscuit	Burst duration (s)	0.37
	Cycle time (s)	0.87**
	Muscle activity (mV·s)	0.92**
	Amplitude (mV)	0.96**
Soft biscuit	Burst duration (s)	0.91**
	Cycle time (s)	0.81**
	Muscle activity (mV·s)	0.98**
	Amplitude (mV)	0.98**
Mungfali gajak	Burst duration (s)	0.97**
	Cycle time (s)	0.91**
	Muscle activity (mV·s)	0.98**
	Amplitude (mV)	0.95**
Til gajak	Burst duration (s)	0.85**
	Cycle time (s)	0.87**
	Muscle activity (mV·s)	0.95**
	Amplitude (mV)	0.95**
Crunch chocolate	Burst duration (s)	0.82**
	Cycle time (s)	0.78**
	Muscle activity (mV·s)	0.16
	Amplitude (mV)	0.98**
Plain chocolate	Burst duration (s)	0.93**
	Cycle time (s)	0.78**
	Muscle activity (mV·s)	0.32
	Amplitude (mV)	0.96**

*$p<0.05$; **$p<0.01$

The principal component analysis of these six representative variables resulted in two meaningful components (Table 8). These components can explain a cumulative proportion of variance of up to 88.7%. The first principal component was having relatively higher values in the order of amplitude per chew, early inter burst duration and early muscle activity, while late inter burst duration and middle amplitude showed higher values for second principal component (Figure 5).

The principal component scores for each food are shown in Table 9. All the foods samples are having different scores indicating their differences in textural attributes while being chewed by human subjects (Figure 6). Both types of biscuits, *gajaks* and chocolates were clustered near to each other indicating closely related textures. These principal component scores were correlated with sensory parameters (Table 10). The scores of first principal component correlated significantly with sensory hardness and chewiness, while scores of second component correlated with sensory adhesiveness.

TABLE 5. Correlation coefficients (r) of two different recordings in an EMG session for early stage mastication parameters.

Food	Parameters	r
Hard biscuit	Burst duration (s)	0.07
	Muscle activity (mV·s)	0.81**
	Amplitude (mV)	0.72*
	Inter burst duration (s)	0.84**
Soft biscuit	Burst duration (s)	0.58
	Muscle activity (mV·s)	0.91**
	Amplitude (mV)	0.88**
	Inter burst duration (s)	0.25
Mungfali gajak	Burst duration (s)	0.92**
	Muscle activity (mV·s)	0.81**
	Amplitude (mV)	0.89**
	Inter burst duration (s)	0.85**
Til gajak	Burst duration (s)	0.60
	Muscle activity (mV·s)	0.78**
	Amplitude (mV)	0.91**
	Inter burst duration (s)	0.80*
Crunch chocolate	Burst duration (s)	-0.18
	Muscle activity (mV·s)	0.90**
	Amplitude (mV)	0.98**
	Inter burst duration (s)	0.94**
Plain chocolate	Burst duration (s)	0.73*
	Muscle activity (mV·s)	0.91**
	Amplitude (mV)	0.96**
	Inter burst duration (s)	0.88**

*p<0.05; **p<0.01

TABLE 6. Correlation coefficients (r) of two different recordings in an EMG session for middle stage mastication parameters.

Food	Parameters	r
Hard biscuit	Burst duration (s)	0.31
	Amplitude (mV)	0.94**
Soft biscuit	Burst duration (s)	0.74*
	Amplitude (mV)	0.97**
Mungfali gajak	Burst duration (s)	0.92**
	Amplitude (mV)	0.93**
Til gajak	Burst duration (s)	0.71*
	Amplitude (mV)	0.94**
Crunch chocolate	Burst duration (s)	0.55
	Amplitude (mV)	0.96**
Plain chocolate	Burst duration (s)	0.57
	Amplitude (mV)	0.87**

*p<0.05; **p<0.01

TABLE 7. Correlation coefficients of two different recordings in an EMG session for late stage mastication parameters.

Food	Parameters	r
Hard biscuit	Inter burst duration (s)	0.93**
	Cycle time (s)	0.92**
Soft biscuit	Inter burst duration (s)	0.94**
	Cycle time (s)	0.89**
Mungfali gajak	Inter burst duration (s)	0.74*
	Cycle time (s)	0.63
Til gajak	Inter burst duration (s)	0.58
	Cycle time (s)	0.71*
Crunch chocolate	Inter burst duration (s)	0.47
	Cycle time (s)	0.46
Plain chocolate	Inter burst duration (s)	0.77*
	Cycle time (s)	0.67*

*$p<0.05$; **$p<0.01$

TABLE 8. Factor loading of the masticatory parameters for each principal component.

Parameter	PC1	PC2
Amplitude per chew	0.506	0.180
Burst duration per chew	0.385	0.232
Late interburst duration	0.141	-0.741
Early muscle activity	0.454	-0.377
Early interburst duration	-0.494	0.132
Muscle activity	0.354	0.453
Cumulative proportion (%)	61.1	88.7

TABLE 9. Principal component scores for the food samples.

Food	PC1 Score	PC2 Score
Hard biscuit	-2.148	0.349
Soft biscuit	-2.709	0.170
Mungfali gajak	1.569	1.649
Til gajak	1.464	0.831
Crunch chocolate	1.138	-1.182
Plain chocolate	0.685	-1.819

TABLE 10. Kendall correlation coefficients between the principal component scores and sensory parameters.

Parameter	PC1	PC2
Hardness	**-0.60****	-0.20
Cohesiveness	-0.15	-0.44
Fracturability	-0.20	0.20
Chewiness	**-0.60****	-0.47
Gumminess	0.20	-0.33
Adhesiveness	-0.28	**-0.55***

*$p<0.20$; **$p<0.15$

FIGURE 1. Setting of EMG electrodes on human subject

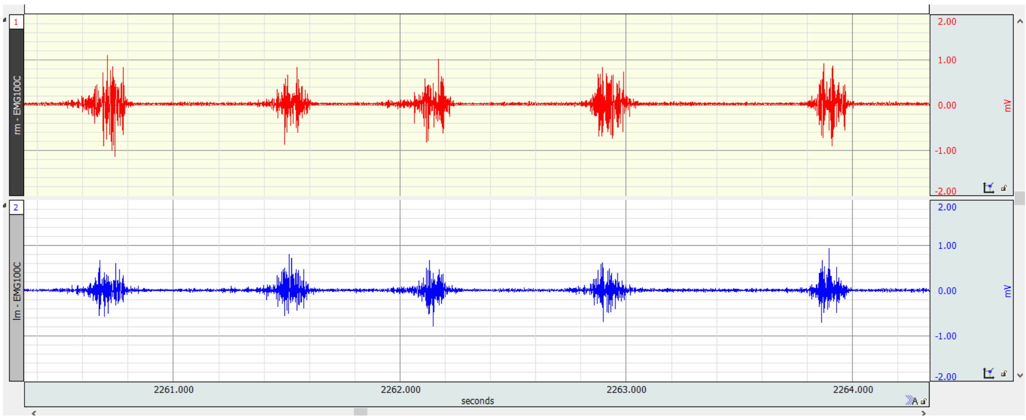
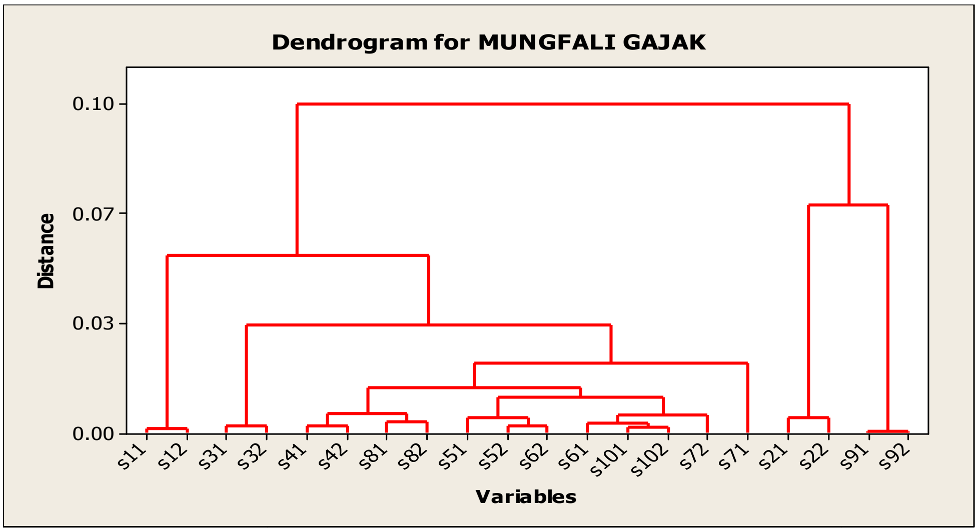
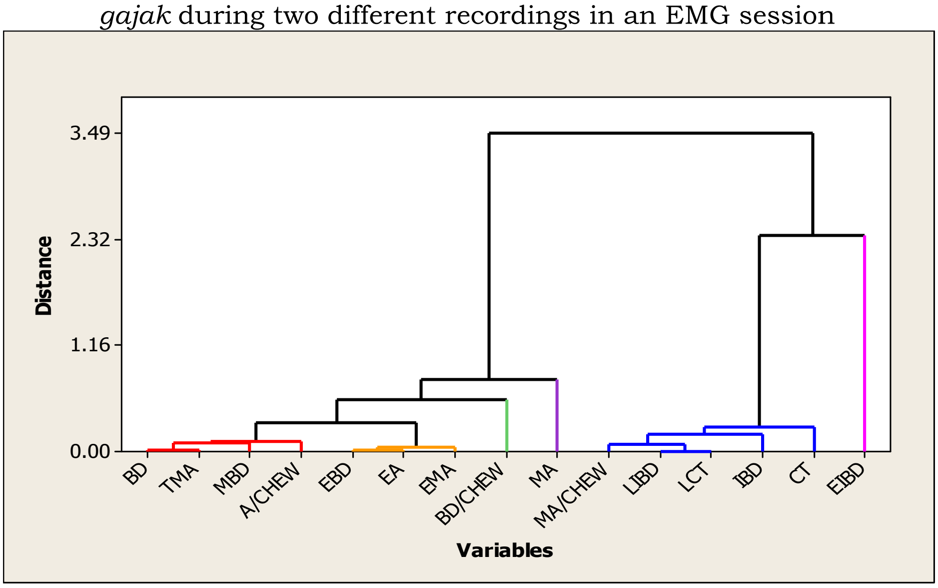


FIGURE 2. Typical EMG chart depicting acquired signals during mastication of food samples



(S11: First subject's first recording; S12: First subject's second recording and so on)

FIGURE 3. Dendrogram showing reproducibility of subjects' chewing behaviour for *mungfali gajak* during two different recordings in an EMG session



(BD: Burst duration; TMA: Total muscle activity; MBD: Middle burst duration; A/Chew: Amplitude per chew; EBD: Early burst duration; EA: Early amplitude; EMA: Early muscle activity; BD/Chew: Burst duration per chew; MA: Middle amplitude; MA/Chew: Muscle activity per chew; LIBD: Late inter burst duration; LCT: Late cycle time; IBD; Inter burst duration; CT: Cycle time per chew; EIBD: Early inter burst duration)

FIGURE 4. Dendrogram for grouping of EMG mastication parameters

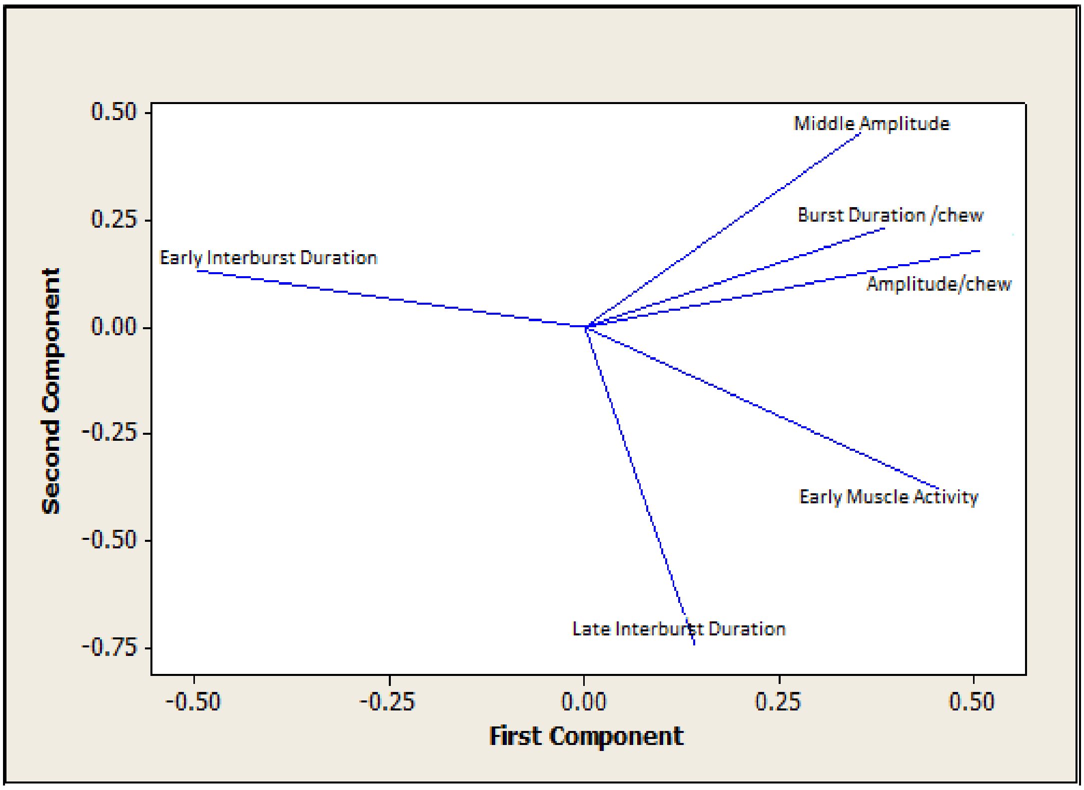


FIGURE 5. Principal component loading plot for EMG mastication parameters

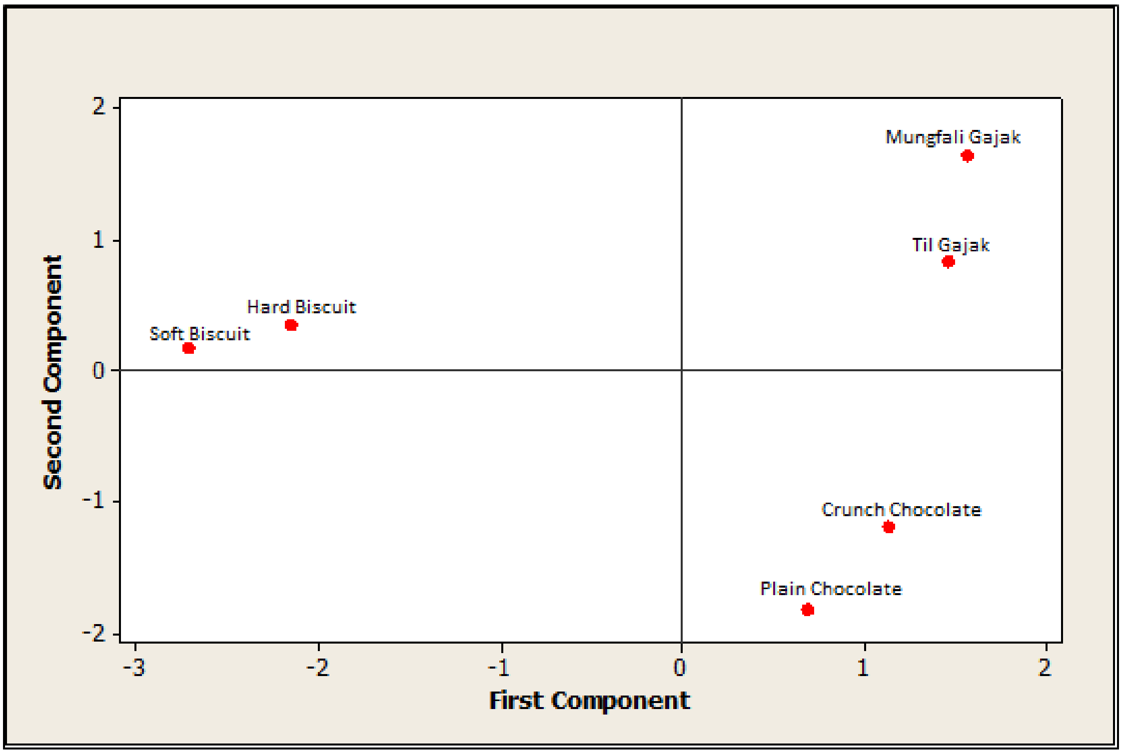


FIGURE 6. Principal component score plot for different foods

CONCLUSION

In this study, emphasis has been laid to prove that EMG is a suitable technique to evaluate different textured food products. The results indicate that out of all the EMG variables studied, amplitude per chew, late inter burst duration, early muscle activity, early inter burst duration and middle amplitude can be used to explain the textural behaviour of food samples investigated in the present study. It is inferred that EMG variables can be significantly related to the human subjects' food texture perceptions. Moreover, EMG system provides the real-time information about the whole chewing process and also emerges as a promising objective method of texture evaluation. Thus this technique needs to be further explored for different foodstuffs in developing standard practices for its application in the food industry.

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CONFLICT OF INTERESTS

Authors declare no conflict of interests.

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