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ORIGINAL ARTICLE

Electromyographic (EMG) investigation of masseter muscle activities acquired in different sessions during chewing of various Indian food products

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ABSTRACT
The objective of this study was to investigate the correlations between electromyographic (EMG) mastication recordings acquired in different sessions during chewing of various Indian food products. Three different sessions were selected for the study viz. one morning session and two evening sessions. Four human subjects participated in the study who were served with five different textured Indian food products. Fifteen mastication variables were obtained by analyzing the data acquired from each EMG session. Correlation studies were conducted for these EMG variables acquired during different sessions. It can be inferred that significant (p≤0.05) correlations exist between EMG variable acquired in the sessions conducted at the same time as well as those conducted at different timings. This indicates that a subject's EMG recordings are reproducible during various sessions.
Keywords: Electromyography, Mastication, Texture, Session.

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INTRODUCTION

Texture is explained as a sensory manifestation of the structure of food in reaction to the applied forces with the involvement of senses like vision, hearing, etc. [21, 5]. The acceptance of food on the basis of its texture depends not only on the consumer's perception but also on the food properties and eating behaviour [19]. To maintain the quality of food and consumer acceptance, food industries must examine textural characteristics of their food products [1].

Meal timings also influence the food textural preferences of consumers. During breakfast foods which can easily get lubricated with saliva, change their structure quickly inside mouth and make a bolus for effortless swallowing are preferred. However, during dinner the consumers have high texture tolerances so they can have foods with varying textures. Actually, as the day progresses the preference of foods having properties linked to enjoyment increases [20].

Textural perception of food can be estimated during mastication based on physiological techniques [3]. Electromyography (EMG) is a non invasive technique which measures the action potential of the motor unit of masticatory muscle when they undergo contraction. The differences in the signals which are generated during chewing of food can be used for the assessment of texture [4]. EMG, being the in-vivo technique, has the potential to provide better textural evaluations as compared to instrumental textural assessments [7]. The pattern of human subject's chewing behaviour also affects the perception of texture [8].

The objective of this study was to investigate the correlations between the EMG variables, obtained from chewing of various Indian foods, acquired during different sessions.

MATERIAL AND METHODS
Subjects and Food Samples
Four female volunteers, who were free from mastication problems, were selected as subjects to participate in this study [10]. Five Indian food samples having different textures were selected namely, cake, *dhokla, paneer,* jelly and *rasgulla*. *Cake*, *dhokla* and *paneer* samples were cut into pieces of 1 cm^3, while jelly and *rasgulla* were given in their original shapes to the human subjects. All subjects gave their informed consent prior to the start of experiment. The conduct of the EMG experiments was approved by Ethical Committee of Guru Nanak Dev University, Amritsar, Punjab, India.

Experimental Set Up and Data Analysis
Human subject was seated comfortably on a chair, took food and masticated it in her regular fashion. Bipolar surface electrodes (EL 503) were placed on both left and right masseter muscles for the recordings of masseter muscle activities [11]. EMG signals were recorded, filtered (10-500Hz) and amplified 1000 times with EMG 100C amplifiers (Biopac System Inc. Goleta, CA). At 1000 Hz frequency EMG signals were stored on PC using MP-150 system (Biopac System Inc. Goleta, CA) [12, 17, 18]. AcqKnowledge software (ver. 4.4, Biopac System Inc., Goleta, CA) was used for the analysis of acquired EMG signals.

Various mastication parameters were studied for entire mastication, per chew mastication and for different stages of mastication viz. early, middle and late [13, 14, 15]. The parameters analyzed were chew number, mastication time, total burst duration, total muscle activity, burst duration, interburst duration, cycle time, muscle activity and amplitude.

Statistical Analysis
ANOVA and correlations analysis were conducted of EMG variables obtained from different sessions (one morning session and two evening sessions) using Minitab statistical software.

RESULTS AND DISCUSSION
During chewing of a particular food in different sessions (morning or evening), relative mean values of EMG parameters were calculated and used in further analysis. The relative values are preferred as these could eliminate inter subject variations [15]. In morning session mastication parameters like no. of chews, mastication time, total burst duration, total muscle activity, cycle time per chew, amplitude per chew, early burst duration, muscle activity (early, middle and late), interburst duration per chew and early amplitude showed significant difference at p≤0.05 (Table 1). Mastication parameters like middle and late amplitude also became significant at a reduced confidence level of p≤0.10. During first evening session (E1) parameters like no. of chews, mastication time, total burst duration, total muscle activity, cycle time per chew, amplitude per chew, middle muscle activity and early amplitude (Table 2) showed significant difference at p≤0.05 for all the foods while late amplitude showed significant differences in foods at p≤0.10. During second evening session (E2) (Table 3) all mastication parameters except muscle activity (early, middle and late), inter burst duration per chew and late amplitude showed significant difference for all the foods at p≤0.05. These results showed that the subjects were able to differentiate the texture of all the foods served to them.

Table1. Electromyographic variables acquired during mastication of five different Indian food samples (morning session, M)

Recordings of morning session (M)	Jelly	Cake	*Dhokla*	*Rasgulla*	*Paneer*	*p* value
No. of chews	0.76	1.00	0.92	1.00	1.32	0.01
Mastication time (s)	0.70	1.06	0.92	1.03	1.29	0.00
Total burst duration (s)	0.77	1.00	0.89	1.06	1.29	0.02
Total muscle activity (mV·s)	0.66	0.99	0.82	1.29	1.24	0.00
Interburst duration per chew (s)	0.88	1.11	1.01	1.03	0.98	0.05
Cycle time per chew (s)	0.92	1.07	0.99	1.04	0.98	0.04
Amplitude per chew (mV)	0.88	1.00	0.91	1.21	0.99	0.02
Early burst duration (s)	0.96	1.01	0.94	1.07	1.02	0.04
Late burst duration (s)	1.06	0.98	0.95	1.05	0.95	0.59
Early muscle activity (mV·s)	0.79	1.07	0.82	1.34	0.99	0.00
Middle muscle activity (mV·s)	0.87	1.00	0.87	1.28	0.98	0.02
Late muscle activity (mV·s)	0.89	0.91	0.95	1.31	0.94	0.05
Early amplitude (mV)	0.79	1.06	0.86	1.28	1.01	0.01
Middle amplitude (mV)	0.91	0.97	0.89	1.22	1.02	0.10
Late amplitude (mV)	0.95	0.89	0.97	1.22	0.97	0.10

Table 2. Electromyographic variables acquired during mastication of five different Indian food samples (first evening session, E1)

Recordings of evening session (E1)	Jelly	Cake	Dhokla	Rasgulla	Paneer	p value
No. of chews	0.76	0.93	0.96	0.89	1.46	0.00
Mastication time (s)	0.77	1.02	0.95	0.90	1.35	0.00
Total burst duration (s)	0.77	0.96	0.92	0.96	1.39	0.00
Total muscle activity (mV·s)	0.69	0.99	0.82	1.15	1.35	0.00
Interburst duration per chew (s)	1.00	1.11	0.99	0.98	0.91	0.13
Cycle time per chew (s)	1.01	1.08	0.98	1.01	0.92	0.05
Amplitude per chew (mV)	0.91	1.05	0.88	1.18	0.97	0.02
Early burst duration (s)	1.66	0.92	0.78	0.79	0.85	0.40
Late burst duration (s)	1.77	0.63	0.90	0.88	0.83	0.31
Early muscle activity (mV·s)	0.59	0.98	0.64	2.01	0.79	0.16
Middle muscle activity (mV·s)	0.36	0.59	0.56	2.90	0.58	0.01
Late muscle activity (mV·s)	0.72	0.82	0.67	2.03	0.76	0.16
Early amplitude (mV)	0.82	1.11	0.89	1.14	1.04	0.05
Middle amplitude (mV)	0.82	1.05	0.92	1.20	1.01	0.25
Late amplitude (mV)	1.01	1.01	0.90	1.18	0.90	0.10

Table 3. Electromyographic variables acquired during mastication of five different Indian food samples (second evening session, E2)

Recordings of evening session (E2)	Jelly	Cake	Dhokla	Rasgulla	Paneer	p value
No. of chews	0.80	0.95	0.97	0.93	1.35	0.00
Mastication time (s)	0.76	1.00	1.01	0.94	1.28	0.00
Total burst duration (s)	0.76	1.00	0.96	0.97	1.31	0.00
Total muscle activity (mV·s)	0.69	0.94	0.98	1.12	1.26	0.00
Interburst duration per chew (s)	0.94	1.05	1.08	0.99	0.94	0.10
Cycle time per chew (s)	0.95	1.05	1.04	1.01	0.95	0.04
Amplitude per chew (mV)	0.93	0.94	1.00	1.16	0.97	0.05
Early burst duration (s)	0.97	1.00	0.95	1.09	1.00	0.05
Late burst duration (s)	0.97	1.14	0.92	1.02	0.95	0.00
Early muscle activity (mV·s)	1.69	0.81	0.77	0.97	0.76	0.64
Middle muscle activity (mV·s)	1.80	0.66	0.83	1.04	0.67	0.53
Late muscle activity (mV·s)	1.81	0.85	0.71	0.97	0.66	0.54
Early amplitude (mV)	0.80	1.06	1.00	1.15	0.99	0.01
Middle amplitude (mV)	1.01	0.87	1.03	1.21	0.90	0.04
Late amplitude (mV)	1.03	1.00	0.96	1.11	0.90	0.51

Table 4. Electromyographic variables acquired during mastication of *Jelly* in first evening session (E1) and second evening session (E2)

Jelly	E1	E2	p value
No. of chews	0.76	0.80	0.63
Mastication time (s)	0.77	0.76	0.86
Total burst duration (s)	0.77	0.76	0.90
Total muscle activity (mV·s)	0.69	0.69	0.95
Interburst duration per chew (s)	1.00	0.94	0.36
Cycle time per chew (s)	1.01	0.95	0.21
Amplitude per chew (mV)	0.91	0.93	0.63
Early burst duration (s)	1.66	0.97	0.32
Late burst duration (s)	1.77	0.97	0.33
Early muscle activity (mV·s)	0.59	1.69	0.28
Middle muscle activity (mV·s)	0.36	1.80	0.16
Late muscle activity (mV·s)	0.72	1.81	0.34
Early amplitude (mV)	0.82	0.80	0.13
Middle amplitude (mV)	0.82	1.01	0.18
Late amplitude (mV)	1.01	1.03	0.88

Table 5. Electromyographic variables acquired during mastication of Cake in first evening session (E1) and second evening session (E2)

Cake	E1	E2	*p* value
No. of chews	0.93	0.95	0.85
Mastication time (s)	1.02	1.00	0.87
Total burst duration (s)	0.96	1.00	0.66
Total muscle activity (mV·s)	0.99	0.94	0.77
Interburst duration per chew (s)	1.11	1.05	0.49
Cycle time per chew (s)	1.08	1.05	0.55
Amplitude per chew (mV)	1.05	0.94	0.22
Early burst duration (s)	0.92	1.00	0.65
Late burst duration (s)	0.63	1.14	0.09
Early muscle activity (mV·s)	0.98	0.81	0.68
Middle muscle activity (mV·s)	0.59	0.66	0.87
Late muscle activity (mV·s)	0.82	0.85	0.94
Early amplitude (mV)	1.11	1.06	0.64
Middle amplitude (mV)	1.05	0.87	0.14
Late amplitude (mV)	1.01	1.00	0.95

Table 6. Electromyographic variables acquired during mastication of *Dhokla* in first evening session (E1) and second evening session (E2)

Dhokla	E1	E2	*p* value
No. of chews	0.96	0.97	0.89
Mastication time (s)	0.95	1.01	0.50
Total burst duration (s)	0.92	0.96	0.48
Total muscle activity (mV·s)	0.82	0.98	0.10
Interburst duration per chew (s)	0.99	1.08	0.15
Cycle time per chew (s)	0.98	1.04	0.10
Amplitude per chew (mV)	0.88	1.00	0.28
Early burst duration (s)	0.78	0.95	0.34
Late burst duration (s)	0.90	0.92	0.95
Early muscle activity (mV·s)	0.64	0.77	0.68
Middle muscle activity (mV·s)	0.56	0.83	0.56
Late muscle activity (mV·s)	0.67	0.71	0.90
Early amplitude (mV)	0.89	1.00	0.26
Middle amplitude (mV)	0.92	1.03	0.29
Late amplitude (mV)	1.01	1.00	0.95

Table 7. Table 4. Electromyographic variables acquired during mastication of *Rasgulla* in first evening session (E1) and second evening session (E2)

Rasgulla	E1	E2	*p* value
No. of chews	0.89	0.93	0.66
Mastication time (s)	0.90	0.94	0.71
Total burst duration (s)	0.96	0.97	0.94
Total muscle activity (mV·s)	1.15	1.12	0.75
Interburst duration per chew (s)	0.98	0.99	0.80
Cycle time per chew (s)	1.01	1.01	0.93
Amplitude per chew (mV)	1.18	1.16	0.66
Early burst duration (s)	0.79	1.09	0.13
Late burst duration (s)	0.88	1.02	0.38
Early muscle activity (mV·s)	2.01	0.97	0.80
Middle muscle activity (mV·s)	2.90	1.04	0.10
Late muscle activity (mV·s)	2.03	0.97	0.24
Early amplitude (mV)	1.14	1.15	0.87
Middle amplitude (mV)	1.20	1.21	0.95
Late amplitude (mV)	1.01	1.00	0.95

Table 8. Electromyographic variables acquired during mastication of *Paneer* in first evening session (E1) and second evening session (E2)

Paneer	E1	E2	*p* value
No. of chews	1.46	1.35	0.06
Mastication time (s)	1.35	1.28	0.02
Total burst duration (s)	1.39	1.31	0.02
Total muscle activity (mV·s)	1.35	1.26	0.12
Interburst duration per chew (s)	0.91	0.94	0.28
Cycle time per chew (s)	0.92	0.95	0.22
Amplitude per chew (mV)	0.97	0.97	0.89
Early burst duration (s)	0.85	1.00	0.47
Late burst duration (s)	0.83	0.95	0.60
Early muscle activity (mV·s)	0.79	0.76	0.93
Middle muscle activity (mV·s)	0.58	0.67	0.81
Late muscle activity (mV·s)	0.76	0.66	0.80
Early amplitude (mV)	1.04	0.99	0.59
Middle amplitude (mV)	1.01	0.90	0.31
Late amplitude (mV)	1.01	1.00	0.95

Table 9. Electromyographic variables acquired during mastication of Jelly in first evening session (E1) and morning session (M)

Jelly	E1	M	*p* value
No. of chews	0.76	0.76	0.96
Mastication time (s)	0.77	0.70	0.10
Total burst duration (s)	0.77	0.77	0.92
Total muscle activity (mV·s)	0.69	0.66	0.39
Interburst duration per chew (s)	1.00	0.88	0.33
Cycle time per chew (s)	1.01	0.92	0.27
Amplitude per chew (mV)	0.91	0.88	0.45
Early burst duration (s)	1.66	0.96	0.33
Late burst duration (s)	1.77	1.06	0.35
Early muscle activity (mV·s)	0.59	0.79	0.28
Middle muscle activity (mV·s)	0.36	0.87	0.03
Late muscle activity (mV·s)	0.72	0.89	0.41
Early amplitude (mV)	0.82	0.79	0.62
Middle amplitude (mV)	0.82	0.91	0.51
Late amplitude (mV)	1.01	0.95	0.49

Table 10. Electromyographic variables acquired during mastication of Cake in first evening session (E1) and morning session (M)

Cake	E1	M	*p* value
No. of chews	0.93	1.00	0.46
Mastication time (s)	1.02	1.06	0.61
Total burst duration (s)	0.96	1.00	0.70
Total muscle activity (mV·s)	0.99	0.99	0.96
Interburst duration per chew (s)	1.11	1.11	0.94
Cycle time per chew (s)	1.08	1.07	0.88
Amplitude per chew (mV)	1.05	1.00	0.33
Early burst duration (s)	0.92	1.01	0.64
Late burst duration (s)	0.63	0.98	0.27
Early muscle activity (mV·s)	0.98	1.07	0.76
Middle muscle activity (mV·s)	0.59	1.00	0.29
Late muscle activity (mV·s)	0.82	0.91	0.66
Early amplitude (mV)	1.11	1.06	0.46
Middle amplitude (mV)	1.05	0.97	0.49
Late amplitude (mV)	1.01	0.89	0.23

Table 11. Electromyographic variables acquired during mastication of *Dhokla* in first evening session (E1) and morning session (M)

Dhokla	E1	M	*p* value
No. of chews	0.96	0.92	0.49
Mastication time (s)	0.95	0.92	0.54
Total burst duration (s)	0.92	0.89	0.88
Total muscle activity (mV·s)	0.82	0.82	0.98
Interburst duration per chew (s)	0.99	1.01	0.19
Cycle time per chew (s)	0.98	0.99	0.26
Amplitude per chew (mV)	0.88	0.91	0.55
Early burst duration (s)	0.78	0.94	0.35
Late burst duration (s)	0.90	0.95	0.80
Early muscle activity (mV·s)	0.64	0.82	0.34
Middle muscle activity (mV·s)	0.56	0.87	0.15
Late muscle activity (mV·s)	0.67	0.95	0.35
Early amplitude (mV)	0.89	0.86	0.16
Middle amplitude (mV)	0.92	0.89	0.61
Late amplitude (mV)	0.90	0.97	0.40

Table 12. Electromyographic variables acquired during mastication of *Rasgulla* in first evening session (E1) and morning session (M)

Rasgulla	E1	M	*p* value
No. of chews	0.89	1.00	0.33
Mastication time (s)	0.90	1.03	0.26
Total burst duration (s)	0.96	1.06	0.39
Total muscle activity (mV·s)	1.15	1.29	0.32
Interburst duration per chew (s)	0.98	1.03	0.58
Cycle time per chew (s)	1.01	1.04	0.64
Amplitude per chew (mV)	1.18	1.21	0.61
Early burst duration (s)	0.79	1.07	0.23
Late burst duration (s)	0.88	1.05	0.36
Early muscle activity (mV·s)	2.01	1.34	0.45
Middle muscle activity (mV·s)	2.90	1.28	0.14
Late muscle activity (mV·s)	2.03	1.31	0.41
Early amplitude (mV)	1.14	1.28	0.26
Middle amplitude (mV)	1.20	1.22	0.94
Late amplitude (mV)	1.18	1.22	0.54

Table 13. Electromyographic variables acquired during mastication of *Paneer* in first evening session (E1) and morning session (M)

Paneer	E1	M	p value
No. of chews	1.46	1.32	0.03
Mastication time (s)	1.35	1.29	0.10
Total burst duration (s)	1.39	1.29	0.13
Total muscle activity (mV·s)	1.35	1.24	0.08
Interburst duration per chew (s)	0.91	0.98	0.29
Cycle time per chew (s)	0.92	0.98	0.19
Amplitude per chew (mV)	0.97	0.99	0.28
Early burst duration (s)	0.85	1.02	0.38
Late burst duration (s)	0.83	0.95	0.46
Early muscle activity (mV·s)	0.79	0.99	0.41
Middle muscle activity (mV·s)	0.58	0.98	0.18
Late muscle activity (mV·s)	0.76	0.94	0.37
Early amplitude (mV)	1.04	1.01	0.60
Middle amplitude (mV)	1.01	1.02	0.95
Late amplitude (mV)	0.90	0.97	0.32

Jelly could be considered as the easiest sample to chew among all the foods used in the present study as the number of chews, mastication time, total muscle activity and total burst duration were found to be the

lowest for this food. While *paneer* was found to be most difficult food to chew as it has highest value for number of chews, mastication time, total muscle activity and total burst duration.

When mastication parameters were compared for recordings took at same timings of two different days viz. first evening session (E1) and second evening session (E2) (Table 4-8), it was found that EMG mastication variables were not significantly different from each other (p≤0.05). Similarly when the EMG variables obtained in first morning session (M) were compared with those obtained in first evening session (E1), no significant differences were found (p≤0.05) for all foods served to the subjects (Table 9-13). The results indicate that the time has no significant effect on the EMG variables obtained from chewing of same foods by same subjects. It can also be stated that EMG sessions conducted at different timings of the day as well sessions conducted at the same timings on different days, generate reproducible results. Earlier studies conducted by Brown *et al.* [2] and Hiiemae [6] also demonstrated that during different sessions the recording of the masseter muscles activities of human subjects remain consistent [2].

CONCLUSION

The present study was undertaken to evaluate the effect of conducting EMG sessions at different timings of a day and same timings of different days on the acquired masseter muscles activities of human subjects when they were served five different food samples viz. jelly, cake, *dhokla, rasgulla* and *paneer.* Most of the EMG variables were able to distinguish the textural differences in these food samples. The results revealed that the acquired EMG variables were not significantly different for the first day morning and evening sessions and for the evening sessions of both days. Thus, indicating that the EMG data is highly reproducible irrespective of its session timings.

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