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A study to investigate reproducibility of chewing behaviour of human subjects within session recordings for different textured Indian foods using electromyography

Sarvesh Rustagi, Navdeep Singh Sodhi and Bhavnita Dhillon

Abstract
The objective of this study was to examine the reproducibility of twelve mastication variables for entire duration of chewing, variables per chew and at three different stages (early, middle and late). Electromyography (EMG) of eight human subjects was conducted for two different recordings in a session. The mastication variables were recorded as the bioelectrical activity of masseter muscles observed during chewing of five different textured foods. Correlation coefficients were found to be statistically significant ($p<0.05$) for two different recordings of foods. Thus it was concluded from this study that chewing behaviour is highly reproducible within a session for human subjects during electromyography.

Keywords: electromyography, masseter muscle, texture, chewing

1. Introduction
There is a dynamic structural change in the food during chewing (Brown *et al.*, 2000) [5]. The differences among the patterns of chewing for different foods can be varied according to the type of muscle through which food is fractured (Sakamoto, 1989) [22]. During chewing EMG activity is affected by texture of food (Karkazis and Kossini, 1997) [9] which can be differentiated on the basis of differences in the various mastication parameters. Thus food characteristics can be correlated with oral physiology (Bilt *et al.*, 2006) [2]. On changing the composition of food their sensory textural perception also changes in terms of chewing behaviour (Cakir, 2011) [6].
Subjects have varying oral processing for texture perception of food (Chen, 2009) [7]. Aging induce some variation in the neuro-muscular activity, which bring about changes in the chewing behaviour (Mioche, 2004) [19]. Mioche and Martin (1998) [20] reported that in terms of muscle work trained members show more variation as compared to naïve subjects during chewing for a given session of EMG.
The breakdown of food in mastication depends on toughness and modulus of elasticity and these parameters show strong relationship between bioelectrical activity and mechanical properties of food (Agrawal *et al.*, 1998) [1]. Masticatory jaw movement is one of the reliable methods to investigate food texture. Various mastication parameters are used for differentiating foods for which human subjects show significant variation (Peyron *et al.*, 1996) [21].
The main objective of this study was to establish correlation between human subject recordings in a given session for various mastication parameters during electromyographic analysis.

2. Materials and Methods
Subjects: Eight human subjects, all female with homogenous facial setup, aged 22 – 28 years (Kohyama *et al.*, 2002) [14], free from any mastication problems were used in this study (Kohyama *et al.*, 2003) [13]. Before starting the experiment, EMG experimental set up was passed by Ethical Committee of Guru Nanak Dev University, Amritsar, Punjab, India. All subjects gave their informed consent prior to the experiment.

2.1 Experimental set up

Human subject was seated comfortably on a chair. Bipolar surface electrodes (EL 503, Biopac system Inc., Goleta, CA) (Kohyama *et al.*, 2014) [16] were placed on both left and right masseter muscles which were identified while the subject clenched the teeth.

Cake, *dhokla* and *paneer* were cut into pieces (10mmx10mmx10mm) weighing 5 grams while *jelly*, *rasgulla* were given in their original shape to the human subjects. Human subjects took food and masticated them in natural manner of chewing because imposed chewing brings error (Kohyama *et al.*, 2004; 2016) [15, 16]. Ten recordings, two of each test food, were made in random order and mean of both recordings were used in the analysis. Throughout the process same environmental conditions were maintained.

2.2 Data and statistical analysis

EMG signals were recorded from both masseter muscles and filtered (10-500Hz) and amplified (×1000) with EMG 100C amplifiers (Biopac System Inc.). EMG signals were stored on PC at 1000 Hz frequency using MP-150 system (Biopac System Inc.) (Sodhi *et al.*, 2010; Kohyama *et al.*, 2016) [23, 17]. EMG signals as shown in (Fig. 1) were studied using AcqKnowledge software (ver. 4.4, Biopac System Inc).

Various mastication parameters were studied for entire mastication duration, mastication variables per chew and mastication parameters for different stages i.e. early, middle and late (Kohyama, 2004) [15]. The parameters analyzed were:

1. Chew number: no. of bursts.
2. Mastication time: total time required for mastication.
3. Total burst duration: addition of time duration of all bursts.
4. Total muscle activity: sum of time integral of all bursts.
5. Burst duration: time difference between start and end of a burst.
6. Interburst duration: time difference between two bursts.
7. Cycle time: sum of duration one burst and one interburst.
8. Muscle activity: time integral of a burst.
9. Amplitude: difference between maximum and minimum value of voltage for a given burst.

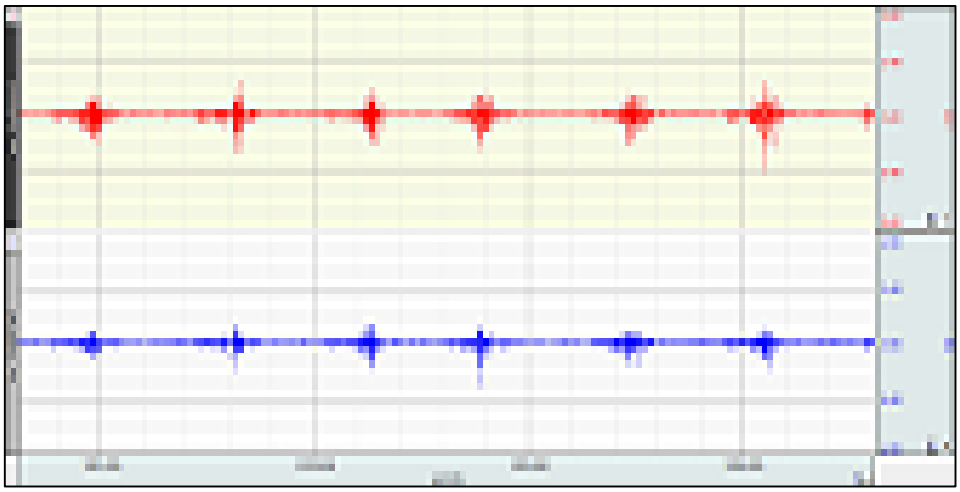

Fig 1: EMG recording for a food.

Correlation was calculated between two recordings of a food for a given parameter at different stages of mastication using Minitab software (ver. 14).

3. Results and Discussion

Table 1: Mean values of two recordings for entire mastication parameters of five different foods.

	Entire Mastication Parameters						
Food	**Recordings**	**Recording 1**		**Recording 2**			
Jelly	Parameters	mean	sd	mean	sd	r	p value
	Chew no.	17.38	7.17	16.25	8.14	0.91	0.00
	Mastication time (s)	14.85	4.83	13.23	5.50	0.69	0.05
	Total burst duration (s)	5.11	2.14	4.32	1.72	0.76	0.03
	Total muscle activity(mV·s)	0.36	0.35	0.34	0.31	0.99	0.00
Cake	Parameters	mean	sd	mean	sd	r	p value
	Chew no.	22.38	8.14	24.00	11.31	0.71	0.05
	Mastication time (s)	18.91	5.92	20.36	7.55	0.57	0.14*
	Total burst duration (s)	6.85	2.94	6.67	2.67	0.75	0.03
	Total muscle activity(mV·s)	0.55	0.35	0.57	0.36	0.91	0.00
Dhokla	Parameters	mean	sd	mean	sd	r	p value
	Chew no.	18.88	6.69	19.38	10.08	0.89	0.00
	Mastication time (s)	15.34	3.76	15.25	6.36	0.85	0.01
	Total burst duration (s)	5.44	1.62	5.10	1.92	0.73	0.04
	Total muscle activity(mV·s)	0.42	0.35	0.43	0.38	0.94	0.00
Rasgulla	Parameters	mean	sd	mean	sd	r	p value
	Chew no.	19.25	6.69	22.50	7.43	0.93	0.00
	Mastication time (s)	15.65	5.31	18.09	5.99	0.80	0.02
	Total burst duration (s)	6.12	2.16	6.54	2.34	0.84	0.01
	Total muscle activity(mV·s)	0.66	0.54	0.74	0.59	0.98	0.00

Paneer	Parameters	mean	sd	mean	sd	r	p value
	Chew no.	30.25	11.36	30.25	11.51	0.97	0.00
	Mastication time (s)	22.85	6.71	22.76	6.92	0.85	0.01
	Total burst duration (s)	8.53	2.44	8.09	2.56	0.87	0.00
	Total muscle activity(mV·s)	0.68	0.51	0.69	0.57	0.99	0.00

Mean and standard deviation values of two recordings for various EMG parameters of five different foods using 8 subjects, r=correlation value, ($p<0.05$) indicate statistically significant value and * indicate non significant value.

During entire mastication level EMG parameters i.e. chew no., mastication time, total burst duration and total muscle activity showed high value of correlation between two recordings taken within same session (Table 1). The result is in accordance with earlier study conducted by Lassauzay *et al.* (2000) [18] in which they explained that there is no difference between mastication parameters for food sample replicates within a session (Karkazis and Kossini, 1998) [10]. All EMG parameters showed statistically significant correlation ($p<0.05$) for five different foods except in case of mastication time for cake. Among all the parameters total muscle activity showed the highest correlation between two recordings.

Table 2: Mean values of two recordings for per chew mastication parameters of five different foods.

	Per Chew Mastication Parameters						
Food	**Recordings**	**Recording 1**		**Recording 2**			
Jelly	Parameters	mean	sd	mean	Sd	r	p value
	Burst duration (s)	0.30	0.07	0.28	0.05	0.31	0.46*
	Inter burst duration (s)	0.58	0.13	0.59	0.19	0.43	0.28*
	Cycle time (s)	0.89	0.14	0.87	0.21	0.48	0.23*
	Muscle activity(mV·s)	0.46	0.87	0.02	0.01	0.75	0.03
	Amplitude(mV)	1.00	0.79	1.06	0.74	1.00	0.00
Cake	Parameters	mean	sd	mean	Sd	r	p value
	Burst duration (s)	0.31	0.04	0.29	0.05	0.93	0.00
	Inter burst duration (s)	0.56	0.10	0.60	0.11	0.68	0.05
	Cycle time (s)	0.87	0.11	0.89	0.13	0.73	0.04
	Muscle activity(mV·s)	0.09	0.18	0.28	0.48	0.23	0.58*
	Amplitude(mV)	1.12	0.62	1.11	0.59	0.99	0.00
Dhokla	Parameters	mean	sd	mean	Sd	r	p value
	Burst duration (s)	0.30	0.07	0.28	0.04	0.75	0.03
	Inter burst duration (s)	0.55	0.13	0.55	0.11	0.62	0.09*
	Cycle time (s)	0.85	0.17	0.82	0.11	0.59	0.12*
	Muscle activity(mV·s)	0.19	0.31	0.16	0.39	0.22	0.60*
	Amplitude(mV)	0.97	0.69	0.98	0.68	0.94	0.00
Rasgulla	Parameters	mean	sd	mean	Sd	r	p value
	Burst duration (s)	0.32	0.05	0.29	0.02	0.24	0.57*
	Inter burst duration (s)	0.52	0.18	0.52	0.08	0.61	0.10*
	Cycle time (s)	0.84	0.19	0.81	0.08	0.53	0.17*
	Muscle activity (mV·s)	0.44	0.88	0.16	0.37	0.17	0.69*
	Amplitude (mV)	1.27	0.69	1.31	0.66	0.99	0.00
Paneer	Parameters	mean	sd	mean	Sd	r	p value
	Burst duration (s)	0.29	0.06	0.27	0.04	0.80	0.02
	Inter burst duration (s)	0.49	0.14	0.50	0.11	0.82	0.01
	Cycle time (s)	0.79	0.14	0.77	0.10	0.88	0.00
	Muscle activity(mV·s)	0.19	0.32	0.15	0.36	0.23	0.59*
	Amplitude (mV)	1.00	0.58	1.05	0.64	1.00	0.00

Mean and standard deviation values of two recordings for various EMG parameters of five different foods using 8 subjects, r=correlation value, ($p<0.05$) indicate statistically significant value and * indicate non significant value.

At per chew mastication level, amplitude is the EMG parameter which showed the highest correlation value between two recordings (Table 2). All EMG parameters showed statistically significant result ($p<0.05$) for five different foods except in case of burst duration (for *jelly and rasgulla*), inter burst duration and cycle time (for *jelly, dhokla and rasgulla*) and muscle activity (for *dhokla, rasgulla, cake and paneer*). These high variations of EMG parameters are due to subject variance for given foods. Brown (1994) [4] showed that mastication behaviour during chewing of foods were highly reproducible during different sessions while inter variation were found among human subjects (Hiiemae, 2004) [8].

Table 3: Mean values of two recordings for early stage mastication parameters of five different foods.

	Early Stage Mastication Parameters						
Food	**Recordings**	**Recording 1**		**Recording 2**			
Jelly	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.26	0.15	0.18	0.15	0.23	0.58*
	Muscle activity(mV·s)	0.02	0.02	0.02	0.01	0.99	0.00
	Amplitude (mV)	0.97	0.75	0.99	0.83	0.97	0.00
Cake	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.20	0.20	0.17	0.16	0.59	0.12*

	Muscle activity (mV·s)	0.03	0.01	0.03	0.01	0.94	0.00
	Amplitude (mV)	1.18	0.68	1.12	0.48	0.91	0.00
Dhokla	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.13	0.16	0.15	0.14	0.85	0.01
	Muscle activity (mV·s)	0.02	0.01	0.02	0.01	0.91	0.00
	Amplitude (mV)	0.94	0.75	0.90	0.65	0.92	0.00
Rasgulla	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.15	0.16	0.17	0.15	0.83	0.01
	Muscle activity (mV·s)	0.27	0.68	0.03	0.02	0.95	0.00
	Amplitude (mV)	1.24	0.60	1.32	0.73	0.88	0.00
Paneer	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.13	0.16	0.16	0.15	0.82	0.01
	Muscle activity (mV·s)	0.02	0.01	0.02	0.01	0.95	0.00
	Amplitude (mV)	1.03	0.76	1.07	0.73	0.96	0.00

Mean and standard deviation values of two recordings for various EMG parameters of five different foods using 8 subjects, r=correlation value, ($p<0.05$) indicate statistically significant value and * indicate non significant value.

Table 4: Mean values of two recordings for middle stage mastication parameters of five different foods.

	Middle Stage Mastication Parameters						
Food	**Recordings**	**Recording 1**		**Recording 2**			
Jelly	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.24	0.16	0.16	0.13	0.55	0.15*
	Muscle activity (mV·s)	0.02	0.02	0.02	0.01	0.98	0.00
	Amplitude (mV)	1.02	0.97	1.01	0.70	0.97	0.00
Cake	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.13	0.16	0.11	0.12	0.68	0.05
	Muscle activity(mV·s)	0.02	0.01	0.02	0.02	0.99	0.00
	Amplitude (mV)	1.14	0.67	1.16	0.74	0.97	0.00
Dhokla	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.16	0.15	0.14	0.13	0.61	0.10*
	Muscle activity (mV·s)	0.02	0.02	0.02	0.02	0.92	0.00
	Amplitude (mV)	1.03	0.76	0.96	0.75	0.92	0.00
Rasgulla	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.13	0.14	0.13	0.13	0.07	0.80*
	Muscle activity (mV·s)	0.33	0.85	0.33	0.25	0.94	0.00
	Amplitude (mV)	1.30	0.68	1.30	0.71	0.98	0.00
Paneer	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.14	0.17	0.15	0.15	0.94	0.00
	Muscle activity (mV·s)	0.02	0.02	0.02	0.02	0.98	0.00
	Amplitude (mV)	0.99	0.62	1.05	0.67	0.96	0.00

Mean and standard deviation values of two recordings for various EMG parameters of five different foods using 8 subjects, r=correlation value, ($p<0.05$) indicate statistically significant value and * indicate non significant value.

Table 5: Mean values of two recordings for late stage mastication parameters of five different foods.

	Late Stage Mastication Parameters						
Jelly	**Parameters**	**mean**	**sd**	**mean**	**sd**	**r**	**p value**
	Burst duration (s)	0.23	0.14	0.17	0.13	0.43	0.28*
	Muscle activity (mV·s)	0.02	0.02	0.02	0.02	0.97	0.00
	Amplitude (mV)	1.03	0.74	1.12	0.84	0.96	0.00
Cake	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.14	0.17	0.11	0.11	0.37	0.37*
	Muscle activity (mV·s)	0.02	0.01	0.03	0.02	1.00	0.00
	Amplitude (mV)	1.11	0.55	1.04	0.61	0.94	0.00
Dhokla	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.11	0.13	0.14	0.14	0.90	0.00
	Muscle activity (mV·s)	0.02	0.01	0.02	0.01	0.94	0.00
	Amplitude (mV)	0.98	0.51	1.04	0.67	0.97	0.01
Rasgulla	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.14	0.15	0.14	0.12	0.32	0.42*
	Muscle activity (mV·s)	0.27	0.68	0.03	0.02	0.94	0.00
	Amplitude (mV)	1.27	0.59	1.32	0.66	0.92	0.00
Paneer	Parameters	mean	sd	mean	sd	r	p value
	Burst duration (s)	0.12	0.16	0.13	0.13	0.90	0.00
	Muscle activity (mV·s)	0.02	0.01	0.02	0.01	0.73	0.04
	Amplitude (mV)	0.95	0.46	0.97	0.57	0.98	0.00

Mean and standard deviation values of two recordings for various EMG parameters of five different foods using 8 subjects, r=correlation value, ($p<0.05$) indicate statistically significant value and * indicate non significant value.

During different stages of mastication i.e. early, middle and late; muscle activity and amplitude showed high correlations (Table 3, 4 and 5). Burst duration did not show correlation at early stages of mastication (for *jelly and cake*), middle stage of mastication (for *jelly, dhokla and rasgulla*) and late stage of mastication (for *jelly, cake and rasgulla*). This was because of bolus formation whose imbalance positioning brings about weak correlation. Kemsley *et al.* (2002) studied the volunteer variance pattern generated during chewing of foods using EMG. They found in between session variation is less than between volunteer variation.

4. Conclusion

In a session similar results were obtained between different recordings for a particular mastication variable of a given food. The high and positive correlation values showed that EMG is reliable technique for measuring food texture and reproduce over time.

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