Original Article

Consistency test for surface electromyography during mastication hints different roles of masseter and anterior temporalis muscles

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Abstract

Objectives This pilot study was designed to ascertain the consistency of electromyography (EMG) activities across participants, recorded from chewing different food samples.

Methods Eight normal subjects and two food taster panelists were recruited. Surface EMG signals were recorded over bilateral anterior temporalis, bilateral masseter, right infrahyoid and right digastric muscles while the participants chewed 8 sessions of each food sample. The samples were shrimp, sausage, carrot and fabricated soft gel. EMG signals were recorded and analyzed with PowerLab and LabChart 8 Pro, respectively. Consistency of muscle activities was determined with an intraclass-correlation coefficient. Unilateral domination of the muscles was determined by congruent domination on electrical activities (area under the curve; AUC) of both the masseter and anterior temporalis.

Results We found that all of the EMG parameters were consistent within participants, however, a few of them showed inconsistency across the population within a food sample. The gel sample showed a unique muscle activity pattern. Unilateral deactivation of muscle activities was found with more profound in non-dominant masseter compared to non-dominant anterior temporalis.

Conclusion We have ascertained that surface EMG is a reliable tool for studying sensorimotor adaptation of the masticatory muscles in response to food textures. Caution should be made in order not to select inconsistent parameters for data analysis. In addition, the difference in activities of the anterior temporalis and masseter muscles suggests the distinct roles of each muscle in mastication.

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Introduction

Sensorimotor adaptation is the physiological process of the central nervous system (CNS) which adjusts the motor outputs in relation to sensory information.[1] The main goal of this adaptation is to accurately modify and maintain appropriate motor commands from dynamic changes of either internal or external environments or both. Even though cellular and molecular mechanisms underlying the learning process occur within the CNS, they ultimately influence motor unit recruitment at the target muscles. Therefore, sensorimotor adaptation can be observed via the electrical activity of the involved muscles using electromyography (EMG) studies.[2]

Mastication (chewing) is an integrated function of the structures within the oral cavity and surrounding muscles to break down food mechanically, which in turn initiates and facilitates digestion and nutrient absorption. It can be divided into 4 phases including stage 1 transport (transport food into the oral cavity), mastication, stage 2 transport (transport the food out of the oral cavity) and deglutition (swallowing).[3] The sensorimotor adaptation can be observed during intraoral food processing, both chewing and swallowing.[4] Intraoral sensory integrations from the food during stage 1 transport and mastication influence motor unit recruitment of the surrounding muscles of mastication. Therefore, different sensations from food characteristics invoke different patterns of masticatory muscle recruitment. A number of studies have reported the patterns of mastication muscle activation in response to different food textures.[5,6] In addition, studying patterns of masticatory muscle activation would also provide insight into the distinct role of each muscle during chewing.[7]

Food texture refers to the perception of food processed intraorally in relation to physical and chemical characters, which is attributed to the food structure and compositions. It was stated in the International Standards Organization (ISO) document that food texture encompasses "… all the rheological and structure (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, and where appropriate, visual and auditory receptors."[8] Sensory receptors, especially intraoral

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ones, are constantly stimulated during a mastication process. In addition, these characteristics are subject to change as the food is broken down mechanically and, to a smaller extent, chemically. Therefore, sensorimotor adaptation continuously updates the motor output to the muscles of mastication. In the view of the food industry, food texture also contributes to food preference, which might also influence customers' choice of food. Using EMG, food texture could be studied objectively which would be a powerful tool to characterize attributes that could gain interest from a wide variety of customers and further develop synthetic foods, for instance, plant-based food and medical food. Nevertheless, the EMG studies so far have never addressed the consistency of the signals across the studied population, making the interpretation questionable.

To test the reliability of surface EMG (sEMG) as a tool for studying masticatory muscle recruitment in relation to food texture, we conducted a small sample size pilot study aiming to confirm the consistency of sEMG for similar types of foods, encompassing both meat and vegetable samples. An equal number of male and female participants were recruited to demonstrate the reliability of sEMG regardless of gender, while food tester panelists are also recruited to demonstrate the reliability regardless of food testing experiences. In addition to food samples, a soft gel sample was fabricated to confirm the concept of sensorimotor adaptation during mastication.

Materials and Methods

Participants and study design

There were 10 participants in this pilot study. Written informed consent was obtained from each individual prior to data collection procedures. Eight normal participants (male = 4, female = 4) together with 2 professional food taster panelists (male = 1, female = 1), who regularly worked with Quantitative Descriptive Analysis (QDA), were recruited. All participants had complete permanent dentition with at least 4 posterior occlusal pairs on each side, normal salivary flow rate, no self-reported xerostomia and no history of orthognathic surgery, temporomandibular disorders, or potential allergic reaction to food. The oral health of all participants was determined by a dentition consultant. EMG signals were obtained while chewing each food sample; there were four samples, each undergoing four sessions of chewing per day spanning over two days. All of the study protocols were reviewed and approved by the Siriraj Internal Review Board (COA: Si 610/2022) according to Declaration of Helsinki and US Federal Policy for the Protection of Human Subjects.

Food sample preparation

Shrimps and sausages were used as representatives for meat and processed meat samples, respectively, while fresh carrots were a representative for vegetables. Gel samples (11% w/w of konjac, carrageenan, modified starch and cellulose in water and oil), representing the extremely soft and compressible food, were used to ascertain the concept of sensorimotor adaptation while chewing. All samples were cut into smaller pieces of 2 cm width, length, or diameter, and kept frozen until the test day. On the test day, food samples were thawed overnight at 4ºC followed by immersion thawing with steam at 20ºC just before serving to the participants. These were the combination of the thawing methods that has been showed previously as the second best shrimp texture preservation, after ultrasonic thawing, which was not available in our laboratory.[9]

EMG recording and analysis

EMG activities were recorded over the bilateral anterior temporalis, bilateral masseter, right infrahyoid and right digastric muscles. Pre-gelled disposable electrodes (Cat. No.019-400400, Natus Medical, Middleton, WI, USA) were placed over the widest diameter of the muscle when it was fully contracted. The bipolar recording was done for the anterior temporalis and masseter, while reference recording (referenced to both heads of the clavicle) was done for the infrahyoid and digastric. Signals were recorded and analyzed with the PowerLab instruments and the LabChart 8 Pro software (ADInstruments, Castle Hill, Australia). Offline signal analysis was also done in the LabChart 8 Pro software for EMG signal quantification.

The EMG attributes along with their definitions and equations for calculation are shown in Table 1. These attributes included the number of chewing sequences, time spent chewing and its details, chewing rate and electrical activities recorded such as amplitude and area under the curve (AUC). Data extracted from raw EMG were exported for further statistical analysis to determine the consistency of the recorded EMG characters from all participants.

To characterize the electrically dominant side and the extent of deactivation on the non-dominant side during soft gel chewing sessions, EMG parameters calculated from four muscles (bilateral anterior temporalis and masseter) were matched for each chewing burst. Then, all parameters were normalized to 100% of the dominant side of each muscle. Bursts that showed congruently dominant on the similar side of both muscles were selected for further analysis. Calculated %AUC were exported for statistical analysis.

Statistical analysis

Intraclass correlation coefficients (ICC) were calculated by SPSS software (IBM Corporation, New York, USA) for statistical demonstration of correlations within each participant and across study population. Coefficient higher than 0.75 was considered high correlation.[10]

Table 1 Attributes extracted from EMG signals recording while food sample chewing of all participants.

Abbrev	Attribute (unit)	Definition/Calculation	Intraclass correlation coefficient			
			Shrimp	Sausage	Carrot	Gel
#Ch	Chew count	Number of bursts observed during chewing	0.973	0.970	0.973	0.968
MChD	Main chewing sequence duration (s)	Time spent to comminute and convert food into a swallowable bolus by chewing	0.869	0.676	0.752	0.889
CD	Clearance duration (s)	Time from stop chewing until swallowing	0.944	0.946	0.935	0.950
TD	Total sequence duration (s)	MChD + CD	0.955	0.967	0.958	0.928
ChR	Chewing rate (s^{-1})	#Ch / TD	0.676	0.884	0.844	0.604
BD	Burst duration (s)	Mean duration of muscle active period	0.511	0.529	0.697	0.611
IBD	Inter burst duration (s)	Mean duration of muscle resting period	0.922	0.947	0.939	0.897
ChCD	Chewing cycle duration (s)	BD + IBD; mean duration of whole chewing cycle	0.834	0.934	0.926	0.834
TBD	Total burst duration (s)	Summation of muscle active period duration	0.958	0.969	0.962	0.945
Mact	Muscle activity of a chewing cycle (µV·s)	Mean AUC of each chewing cycle	0.957	0.982	0.979	0.971
MxF	Maximum amplitude (µV)	Maximal amplitude of EMG signals	0.986	0.982	0.515	0.682
MeF	Mean amplitude (µV)	Mean amplitude of EMG signals	0.966	0.972	0.952	0.957
TMW	Total muscle work (energy) (µV·s)	Summation of AUC extracted from the whole sequence	0.252	0.672	0.700	0.689
AgW	Average work per chewing cycle (µV·s/chew)	TMW / #Ch	0.975	0.989	0.977	0.948
ChWR	Chew work rate (mV^2/sec)	TMW / MChD	0.984	0.99	0.981	0.975

Parameters from each participant were averaged for comparison of the whole population. Parameters that showed inconsistency were signified with red color. AUC, area under the curve.

Calculated %AUC were imported into GraphPad Prism software (GraphPad Software, San Diego, CA, USA). One-way ANOVA followed by Tukey post hoc test was performed to determine differences in %AUC within each individual and mean %AUC across the population. Statistically significant was considered at p value less than 0.05.

Results

EMG parameters showed high consistency

ICC calculated within each participant showed high consistency in all samples (data not shown). Therefore, we continued further analysis within the population using average values from each participant. Our results showed that the ICC coefficients were high in a number of parameters. Most primary parameters showed high consistency across participants, except burst duration (BD), maximal EMG amplitude (MxF) and total muscle work (TMW). Almost all parameters derived from primary ones were also highly correlated, except only chewing rate (ChR).

Unilateral deactivation of masseter and anterior temporalis was observed from gel sample sessions

To ensure that the EMG results represented sensorimotor adaptation, gel samples were fabricated by mixing konjac, carrageenan, starch and cellulose as a negative control. We hypothesized that, with soft, compressible food, EMG signals should be reduced over time during mastication. The EMG results, however, showed that muscle activities did not reduce while food was undergoing processing (Figure 1). The EMG burst from each chew remained constant until the food processing finished. Yet, we observed that there was inconsistency in EMG burst size when two sides of the mastication muscles, both anterior temporalis and masseter, were compared. The electrical activity of the muscles was larger on one side, which can be switched when participants switched the location of the food bolus. The same observation can be appreciated both in panelist (Figure 1A and 1B) and non-panelist (Figure 1C and 1D) participants. Interestingly, when the panelist participants were instructed to chew as they were appraising the QDA, high bursts of EMG signals were recorded from all of the muscles. However, the deactivation on one side of the muscles can still be observed (Figure 1B).

Deactivation was more pronounced in non-dominant masseter than that of non-dominant anterior temporalis

Muscle electrical activities were typically shown by the maximum EMG amplitude (MxF) or AUC (Mact) calculated from the extracted EMG parameters. Therefore, AUC was chosen to represent the muscle activity since it showed consistency across all participants, while the amplitude was not. AUCs were then normalized to 100% of AUC on the dominant side. One-way ANOVA analysis revealed that not only dominant sides were significantly higher in %AUC compared to non-dominant sides, but the average %AUC of non-dominant anterior temporalis was also significantly higher than that of the non-dominant masseter ($p = 0.029$). (Figure 2)

The mean %AUC from all participants is shown in Table 2. One-way ANOVA analysis showed that the majority of the population (70%) exhibited a significant difference in %AUC between non-dominant masseter and non-dominant anterior temporalis. Out of seven participants, six showed greater deactivation in the masseter compared to the anterior temporalis, while one showed an opposite result. The remaining three participants showed no statistical difference in deactivation between the two muscles.

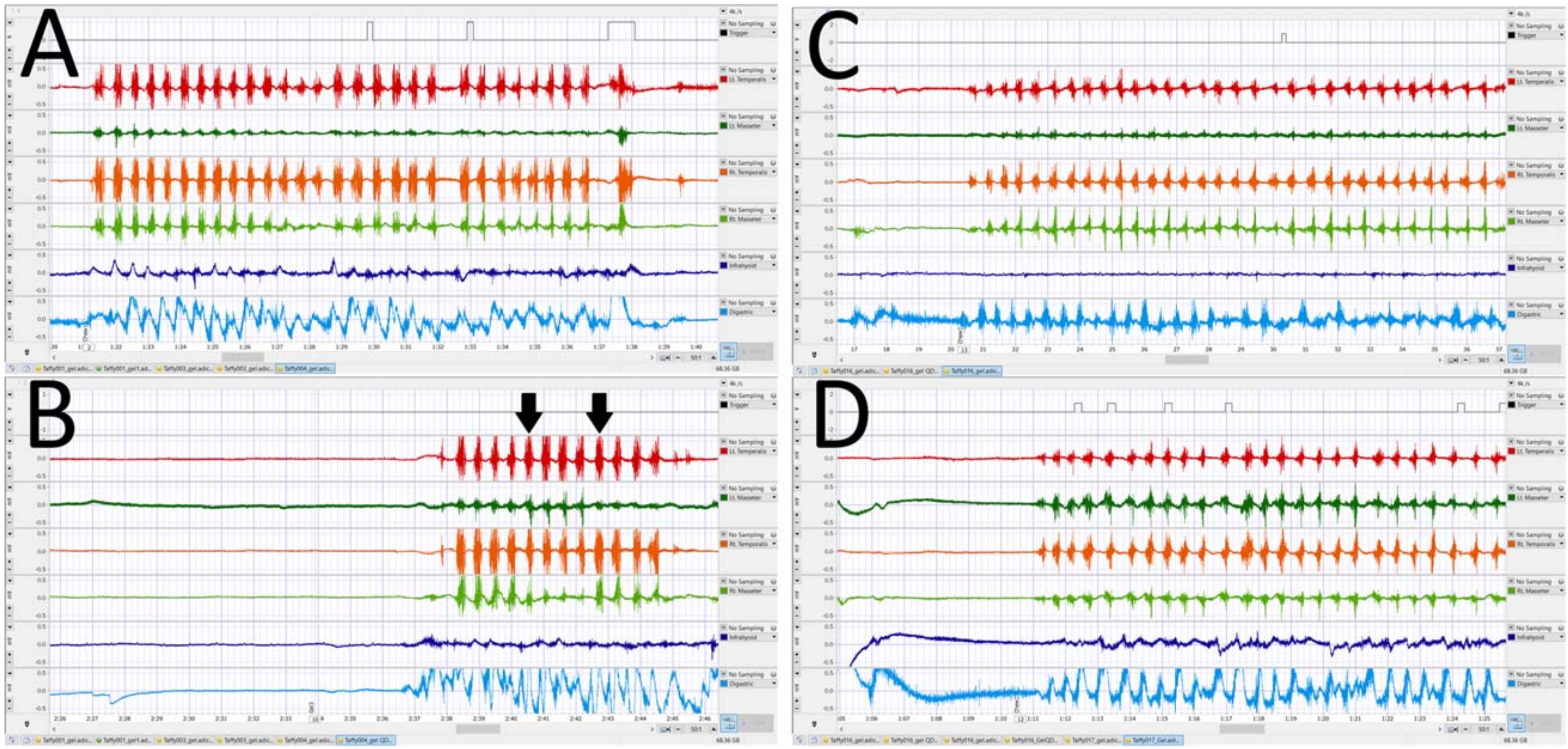

Figure 1 Unilateral deactivation of masseter and anterior temporalis can be observed in both panelist and non-panelist participants.
Representative EMG activities recorded from participants showing signals from left anterior temporalis (*red*), left masseter (*dark green*), right anterior temporalis (*orange*), right masseter (*light green*), infrahyoid (*purple*), and digastric muscles (*light blue*). (*A* and *B*) Representative EMG activities recorded from a panelist participant during normal chewing (*A*) and QDA analysis (*B*). The arrows denote the side changes of muscle deactivation, which correspond with the chewing side. (*C* and *D*) Representative EMG activities recorded from a non-panelist participants.

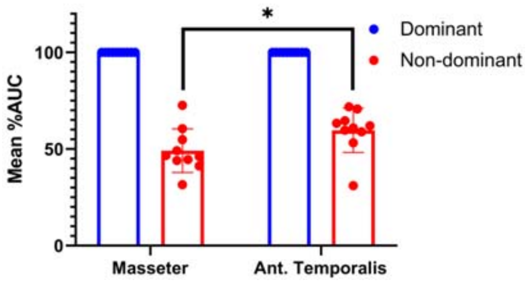

Figure 2 Deactivation of non-dominant masseter was more pronounced than that of anterior temporalis.
Analysis of average percent AUC across all 10 participants with one-way ANOVA followed by Tukey *post hoc* test showed that average percent AUC of muscle activity in non-dominant masseter was significantly lower than that of non-dominant anterior temporalis. *, $p < 0.05$

Discussion

Our results suggest that EMG is a reliable tool to study the correlation between intraoral food processing and food texture. Parameters extracted from EMG signals were consistent across food samples and subjects, regardless of gender or whether or not they have prior experience with food testing. A recent report using surface EMG to assess facial muscle function in ALS patients (n = 13) also confirmed that EMG signals were "internally consistent and valid."[11] However, we have found that not all parameters were consistent. ChR, BD, MxF and TMW showed inconsistency, suggesting that they were subject to high interpersonal variability. Inconsistency of surface EMG attributes, especially maximal EMG amplitude, has been reported elsewhere.[12] Despite differences among EMG parameters in relation to types of food samples observed in our investigation, this study was not designed to answer whether EMG attribute(s) can distinguish among food textures. Therefore, we decided not to disclose our detailed analysis until we have conducted a properly designed study (data not shown).

The function of both anterior temporalis and masseter muscles is jaw-closing, even though their muscle origins and insertions are different. They contracted in concert with each other. These muscle electrical activities during jaw clenching were shown to be complement and able to substitute for their partner.[13] The distinguished roles of these 2 muscles have not been well documented. Most studies have shown that both muscles are similar in either functional study in humans[14] or molecular study in mice.[15] An EMG study of masseter and anterior temporalis after lower third molar extraction suggested more involvement in mastication of anterior temporalis based on higher muscle activity.[16] It is intriguing that no prior study has reported differences between anterior temporalis and masseter. Here, our results have replicated the dominant activity of masseter on the chewing side while processing gel samples,[17,18] however dominant activity of anterior temporalis has never been shown elsewhere.

These results can be evidence for activities of both muscles in relation to mastication. While both muscle electrical activities diminished on the non-dominant side, reduced activity was greater in the non-dominant masseter compared to anterior temporalis. There are a few possible explanations for the observed phenomenon. When considering the soft nature of the gel sample, greater deactivation of non-dominant masseter might reflect adaptation where force for grinding food is not needed. From this viewpoint, our data suggested that anterior temporalis muscles could be important for initiating and maintaining jaw movements, while masseter muscles are important for providing enough force for food disintegration mechanically.

The processes of sensorimotor adaptation include both the explicit component, which adapts the motor control from conscious recognition of errors through extensive learning, and the implicit component, which adjusts the control automatically outside the awareness.[19] Visual information is seen as the major sensory input for the adaptation. Evidence has pointed out that proprioception is also fundamental to implicit unaware adaptation[20], presumably including the mechanism which governs mastication. The neural process controlling muscles of mastication occurs bilaterally to accommodate the control over the single mandible.[7] The nature of human chewing

Table 2 Average percent AUC of non-dominant masseter and anterior temporalis muscles compared to dominant side during chewing session of gel samples in each participant.

Participant	Masseter		Anterior temporalis		Number of chewing bursts		*p* value*
	Dominant	Non-dominant	Dominant	Non-dominant	Total	Analyzed	
1	100	72.11 ± 20.73	100	68.63 ± 22.86	170	99	0.39
2		46.58 ± 26.23		56.66 ± 23.19	331	163	< 0.0001
3		31.33 ± 21.35		59.14 ± 21.88	142	89	< 0.0001
4		44.00 ± 23.87		64.67 ± 22.37	197	76	< 0.0001
5		44.53 ± 25.27		31.01 ± 30.32	209	120	< 0.0001
6		46.16 ± 24.19		59.74 ± 23.60	189	85	< 0.0001
7		49.12 ± 24.60		53.24 ± 23.33	244	131	0.20
8		41.27 ± 26.40		58.92 ± 25.59	237	169	< 0.0001
9		54.88 ± 27.21		71.88 ± 20.15	176	76	< 0.0001
10		60.51 ± 24.05		63.36 ± 21.70	89	45	0.84

*Tukey *post hoc* comparison between non-dominant masseter and non-dominant anterior temporalis.

behavior, however, often occurs unilaterally.[21] This discrepancy creates a differential load for muscles to overcome on each side, which is where sensorimotor adaptation helps adjust motor output in appropriate proportion to the load. The role of muscle deactivation on the non-chewing side is still unknown. We hypothesized that as higher loads are applied to both sides of the muscle while processing harder food samples, higher muscle activation is needed bilaterally for efficient jaw-closing movement to disintegrate food samples. This creates virtually undetectable differences in muscle activities, even though the adaptation is still applied to the non-chewing side. When a minimal load was applied while chewing the fabricated gel samples, the non-chewing side is off-loaded which in turn results in higher suppression of muscle activities.

A major weakness in this study is the analysis bias for dominant and non-dominant EMG signals. Since the chewing side was not recorded during the experimental sessions, the dominant side was determined by the concomitant domination of the muscular activities of both the masseter and the anterior temporalis during offline analysis. Even though this method ascertains the dominance of the muscle, other possibilities were filtered out, for example, one muscle on the chewing side might be deactivated. We are determined to reduce this bias and a more proper designed experiment is being planned to support this hypothesis.

Food texture analysis with QDA described food from intraoral sensation while chewing.[22] We observed that, while panelist participants performed QDA, EMG activities of all masticatory muscles amplified (Figure 1B). This could explain the nature of QDA testing which the panelists needed to intentionally maximize motor output to override the sensorimotor adaptation, in order to fully appreciate the intraoral sensation from food. However, unilateral deactivation of both muscles, especially the masseter, can still be observed in panelists during QDA sessions. It would be interesting to study deeper into the mastication muscle activities in panelists while performing QDA.

Conclusion

Our results showed that the EMG characteristics were consistent across food samples and characteristics of participants, regardless of gender and whether they were professional food taster panelists or not. Therefore, EMG can be used for the objective characterization of food textures. Even though the pattern of muscle activation in each type of texture is not covered in this study, high correlation of EMG parameters across participants suggests that it can be used to obtain textural information about interesting food from the wider population, instead of from a limited number of food tester panelists alone. In addition, the EMG signals recorded while gel chewing showed unilateral deactivation of masticatory muscles. This finding has hinted at the different roles of the anterior temporalis and masseter muscles while chewing. As the former might be important for maintaining jaw movement, the latter might be more involved in providing enough force for breaking food mechanically.

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Conflict of Interest

U.S. was employed by Thai Union Group PCL, who supported the study. Other authors have no financial nor conflict of interest to disclose.

Author Contribution

[CRediT author statement] **Usanee Sotthiwat**: Conceptualization, Investigation, Formal analysis, Writing – review and editing; **Traiphop Dokmai**: Resources, Investigation, Data curation, Writing – review and editing; **Sujiwan Seubbuk Sangkhamanee**: Dentition specialist, Formal analysis, Data curation, Writing – review and editing; **Sompol Tapechum**: Methodology, Formal analysis, Data curation, Writing – review and editing; **Rujapope Sutiwisesak**: Funding acquisition, Conceptualization, Investigation, Formal analysis Writing – original draft preparation; Writing – review and editing. All authors have seen and approved the final version of the manuscript

References

1. Della-Maggiore V, Landi SM, Villalta JI. Sensorimotor adaptation: multiple forms of plasticity in motor circuits. Neuroscientist. 2015; 21: 109-25.
2. Iturralde PA, Torres-Oviedo G. Corrective muscle activity reveals subject-specific sensorimotor recalibration. Eneuro. 2019; 6: ENEURO.0358-18.2019.
3. Hiiemae KM, Palmer JB. Food transport and bolus formation during complete feeding sequences on foods of different initial consistency. Dysphagia. 1999; 14: 31-42.
4. Avivi-Arber L, Lee JC, Sessle BJ. Chapter 9 - Face sensorimotor cortex neuroplasticity associated with intraoral alterations. Prog Brain Res. 2011; 188: 135-50.
5. Mioche L, Bourdiol P, Martin JF, Noël Y. Variations in human masseter and temporalis muscle activity related to food texture during free and side-imposed mastication. Arch Oral Biol. 1999; 44: 1005-12.
6. Lee HJ, Park YS, Choi KJ, et al. Impact of varying food hardness on mastication/swallowing. Food Sci

Biotechnol. 2023;32: 959-67.
7. de Jong WC, Korfage JA, Langenbach GE. The role of masticatory muscles in the continuous loading of the mandible. J Anat. 2011; 218: 625-36.
8. International Organization for Standardization. Sensory analysis – Vocabulary (ISO Standard No. 5492:2008). 2008; Available from https://www.iso.org/standard/38051.html.
9. Sun Y, Luo W, He M, Zhao Y, Sun J, Mao X. Effects of different thawing methods on the physicochemical properties and myofibrillar protein characteristics of *Litopenaeus vannamei*. LWT – Food Sci Tech. 2024; 192: 115668.
10. Liljequist D, Elfving B, Skavberg Roaldsen K. Intraclass correlation – A discussion and demonstration of basic features. PLoS One. 2019; 14: e0219854.
11. Rong P, Pattee GL. A multidimensional facial surface EMG analysis for objective assessment of bulbar involvement in amyotrophic lateral sclerosis. Clin Neurophysiol. 2022; 135: 74-84.
12. Kleissen RFM, Litjens MCA, Baten CTM, Harlaar J, Hof AL, Zilvold G. Consistency of surface EMG patterns obtained during gait from three laboratories using standardised measurement technique. Gait Posture. 1997; 6: 200-9.
13. Farella M, Palumbo A, Milani S, Avecone S, Gallo LM, Michelotti A. Synergist coactivation and substitution pattern of the human masseter and temporalis muscles during sustained static contractions. Clin Neurophysiol. 2009; 120: 190-7.
14. Gomes SGF, Custodio W, Faot F, Del Bel Cury AA, Garcia RCMR. Masticatory features, EMG activity and muscle effort of subjects with different facial patterns. J Oral Rehabil. 2010; 37: 813-9.
15. Abe S, Hiroki E, Iwanuma O, et al. Relationship between function of masticatory muscle in mouse and properties of muscle fibers. Bull Tokyo Dent Coll. 2008; 49: 53-8.
16. Buesa-Bárez JM, Martin-Ares M, Martínez-Rodriguez N, et al. Masseter and temporalis muscle electromyography findings after lower third molar extraction. Med Oral Patol Oral Cir Bucal. 2018; 23: e92-7.
17. Kohyama K, Gao Z, Ishihara S, Funami T, Nishinari K. Electromyography analysis of natural mastication behavior using varying mouthful quantities of two types of gels. Physiol Behav. 2016; 161: 174-82.
18. Kohyama K, Hayakawa F, Kazami Y, et al. Electromyographic texture characterization of hydrocolloid gels as model foods with varying mastication and swallowing difficulties. Food Hydrocoll. 2015; 43: 146-52.
19. Tsay JS, Kim H, Haith AM, Ivry RB. Understanding implicit sensorimotor adaptation as a process of proprioceptive re-alignment. Elife. 2022; 11: e76639.
20. Crevecoeur F, Munoz DP, Scott SH. Dynamic multisensory integration: somatosensory speed trumps visual accuracy during feedback control. J Neurosci. 2016; 36: 8598-611.
21. Diernberger S, Bernhardt O, Schwahn C, Kordass B. Self-reported chewing side preference and its associations with occlusal, temporomandibular and prosthodontic factors: results from the population-based Study of Health in Pomerania (SHIP-0). J Oral Rehabil. 2008; 35: 613-20.
22. de Lavergne MD, van de Velde F, van Boekel MAJS, Stieger M. Dynamic texture perception and oral processing of semi-solid food gels: Part 1: Comparison between QDA, progressive profiling and TDS. Food Hydrocoll. 2015; 43: 207-17.