



Masticatory Muscle Activity in Individuals with Restrained Eating Behavior: a Cross-Sectional Study

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ABSTRACT

INTRODUCTION. The prevalence of overweight and obesity has long been a global public health problem that becomes more acute every year. To increase the effectiveness of weight loss programs based on dietary restriction, including those used in the health resort treatment, it is necessary to take into account individual physiological characteristics associated with restrained eating behavior.

AIM. To measure electromyographic (EMG) parameters of masticatory muscle activity in restrained eaters during an agar chewing test.

MATERIALS AND METHODS. A cross-sectional study was conducted with 129 untrained participants (83 women and 46 men, mean age 32.4 ± 8.1 years) who were categorized as non-restrained (control) and restrained eaters based on scores on the restrained scale of the Dutch Eating Behavior Questionnaire. EMG parameters of masticatory, temporalis, and suprahyoid muscle activity were determined in the initial, middle, and final phases of the chewing test.

RESULTS AND DISCUSSION. Restrained eaters chewed agar gels with the same frequency (1.40 vs. 1.44 sec^{-1} , $p = 0.305$), using the same number of chewing movements (31.9 vs. 35.0 times, $p = 0.979$) and duration of chewing (23.2 vs. 24.2 s , $p = 0.710$) in comparison to controls. The maximal and mean amplitudes of the masseter muscle signal in restrained eaters were 17 % lower than in controls, despite the chewing cycle duration and frequency being similar. Regardless of eating behavior, the maximal and mean amplitudes of the EMG signal of contraction in the temporalis muscle were 18–21 % and 15–17 % lower than those in the masseter muscle, respectively. The maximal amplitude of the suprahyoid muscle's EMG signal showed no differences across groups; however, the mean amplitude was 18 % lower in restrained eaters compared to controls. The activity of the masseter and temporalis muscles was reduced in the initial phases of chewing, whereas the activity of the suprahyoid muscles was reduced in the final phase of bolus formation and swallowing.

CONCLUSION. Restrained eaters demonstrated reduced masticatory muscle activation in the chewing test. It is advisable to identify restrained eating behavior and assess chewing function when prescribing calorie-restricted dietary therapy to patients in health resort treatments. Medical rehabilitation of patients with restrained eating behavior should include the use of treatment technologies aimed at restoring the activity of the masticatory muscles.

KEYWORDS: restrained eating behavior, chewing test, electromyography, masseter muscle, temporalis muscle, suprahyoid muscles

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Активность жевательных мышц у лиц с ограничительным типом пищевого поведения: поперечное исследование

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РЕЗЮМЕ

ВВЕДЕНИЕ. Распространенность избыточного веса и ожирения уже давно является глобальной проблемой общественного здравоохранения, которая с каждым годом становится все острее. Для повышения эффективности программ по снижению веса, основанных на ограничении питания, в том числе применяемых в санаторно-курортном лечении, необходимо учитывать индивидуальные физиологические особенности, связанные с ограничительным пищевым поведением.

ЦЕЛЬ. Измерение параметров электромиографической (ЭМГ) активности жевательных мышц у лиц с ограничительным пищевым поведением во время агаровой жевательной пробы.

МАТЕРИАЛЫ И МЕТОДЫ. Поперечное исследование проведено с участием 129 неподготовленных испытуемых (83 женщины и 46 мужчин, средний возраст — $32,4 \pm 8,1$ года), которые были разделены на группу неограничительного (контроль) и ограничительного типа с помощью ограничительной шкалы Голландского опросника пищевого поведения. Параметры ЭМГ активности жевательной, височной и надподъязычных мышц были определены в начальную, среднюю и финальную фазу пережевывания агаровой жевательной пробы.

РЕЗУЛЬТАТЫ И ОБСУЖДЕНИЕ. Лица с ограничительным пищевым поведением жевали пробу с одинаковой частотой ($1,40$ vs. $1,44$ с⁻¹, $p = 0,305$), количеством жевательных движений ($31,9$ vs. $35,0$ раза, $p = 0,979$) и продолжительностью жевания ($23,2$ vs. $24,2$ секунды, $p = 0,710$), что и лица в контрольной группе. Максимальная и средняя амплитуды ЭМГ-сигнала жевательной мышцы у лиц ограничительного типа были на 17 % ниже, чем в контрольной группе, несмотря на то что продолжительность и частота жевательных циклов у них были сходными. Независимо от пищевого поведения максимальная и средняя амплитуды ЭМГ-сигнала при сокращении височной мышцы были на 18–21 % и 15–17 % ниже, чем в жевательной мышце, соответственно. Максимальная амплитуда ЭМГ-сигнала надподъязычных мышц не показала различий между группами; однако средняя амплитуда ЭМГ-сигнала была на 18 % ниже у людей ограничительного типа по сравнению с контрольной группой. Рабочая активность жевательной и височной мышц была снижена в начале жевания, тогда как активность надподъязычных мышц была снижена в конце жевания, на этапе формирования пищевого комка и глотания.

ЗАКЛЮЧЕНИЕ. Лица с ограничительным пищевым поведением характеризуются пониженной активацией жевательных мышц при пережевывании жевательной пробы.

КЛЮЧЕВЫЕ СЛОВА: ограничительное пищевое поведение, жевательная проба, электромиография, жевательная мышца, височная мышца, надподъязычные мышцы

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INTRODUCTION

The prevalence of overweight and obesity has long been a global public health problem that becomes more acute every year [1]. Obesity/overweight is generally associated with cardiovascular and metabolic diseases, which in turn can cause early disability and mortality [2]. New insights into the pathophysiology of obesity have led to the development of promising pharmacological targets and therapeutic techniques to combat the global obesity epidemic and associated comorbidities. However, there are only a few licensed pharmacotherapies for treating obesity, and their success has been low [3]. Therefore, beyond pharmacotherapy, there is an urgent need to develop other promising noninvasive antiobesity strategies, including various weight management programs.

A common response to weight gain is dietary restriction, which is the basis of most traditional weight loss programs [4].

In particular, moderate restriction of energy value to 1300–1600 kcal/day (mainly due to fats and carbohydrates) is indicated in the health resort treatment of alimentary obesity, type 2 diabetes mellitus with obesity, and cardiovascular diseases in the presence of excess weight [5]. Diet therapy based on reducing caloric intake is also included in the complex of medical rehabilitation measures for oncogynecological patients [6]. However, it is increasingly evident that dietary restraint is often unsuccessful, and restrained eaters tend to have a higher body mass index (BMI) than unrestrained eaters. Adhering to a diet is notoriously stressful, and long-term weight-loss maintenance is often poor. It is currently believed that increasing the effectiveness of weight loss programs requires considering numerous individual difference aspects associated with restrained eating.

Mastication, as the initial stage of digestion, influences the quality of mechanical and chemical processing of

food [7, 8]. In addition, mastication promotes better sensory perception of food [9] as well as enhances satiety and satiation [10]. Individual differences in masticatory behavior are mostly determined by physiological factors such as age, gender, dental condition, masticatory muscle activity, obesity status, and others [11–14]. Taking into account individual variability in chewing, we hypothesize that restrained eating behavior influences chewing parameters. In particular, people with restrained eating are suggested to experience weakened masticatory muscle activity. Our hypothesis is based on the notion that decreased chewing activity may contribute to restrained eating by decreasing chewing's anti-stressful effect. Furthermore, poor masticatory activity may result in decreased emotional control and impairment in cognitive functions. It has been shown that restrained eating behavior is characterized by an impairment in cognitive functions [15], weakened emotional regulation [16], and increased craving for palatable food [17]. At the same time, it is known that cognitive function impairment [18], negative psycho-emotional state [19], and high palatability of consumed food [20] are associated with changes in chewing structure. Characterization of chewing activity in people with restrained eating behavior is necessary to test this hypothesis and may help understand the causes leading to increased body weight.

The aim of the study was to measure electromyographic (EMG) parameters of masticatory muscle activity in restrained eaters during an agar chewing test.

MATERIALS AND METHODS

Participants

The study was approved by the Local Ethics Committee of the Institute of Physiology of Federal Research Centre "Komi Science Centre of the Urals Branch of the Russian Academy of Sciences" (Protocol No. 10 dated 10.03.2022). For the study, men and women aged 18 to 45 without oral cavity pathology and missing teeth were invited. These were students and researchers. The study involved 129 individuals (64 % female), with an average age of 31.7 ± 8.2 years and a BMI of 24.5 ± 4.0 kg/m². Before the start of the study, each participant was familiarized with the protocol of the study and provided written informed consent.

Protocol of study

The testing was conducted from 11 to 14 PM in a sensory room, taking into account the requirements of ISO 8589:2007. Participants were asked to refrain from eating and drinking for at least one hour before the testing. Before testing began, they filled out a questionnaire in which they indicated their gender, age, height, weight, and subjective feelings of hunger and stomach fullness. The height and weight of the participants were measured using bathroom scale and a height meter, respectively. Subjective appetite sensations were assessed using a 100-mm visual analog scale with words anchored at each end, "not at all" and "very".

For the chewing test, an agar gel with a 6 % agar concentration was used. The preparation method and mechanical characteristics of the chewing test were detailed earlier [21]. Chewing tests were prepared the day before testing and heated to room temperature before being given to participants. Each participant was asked to chew the

chewing test in their usual manner and swallow it. During this time, the EMG activity of the masticatory muscles was recorded to characterize their chewing behavior. At the end of the testing, participants filled out the Dutch Eating Behavior Questionnaire. The measurement of the masseter muscle thickness was conducted on another scheduled day.

Measures

Eating behavior

Restrained eating behavior of participants was assessed using the restrained scale of the Dutch Eating Behavior Questionnaire (DEBQ_{Res}) [22]. The scale consists of 10 questions related to restrained eating, for example, "Take into account weight when eat..." For each question, participants had to choose one of five response options: "never or very rarely", "seldom", "sometimes", "often", or "always or very often". The Russian version of the questionnaire showed a high level of internal consistency and reliability in measuring restrained eating behavior [23]. The median score was used as the cutoff value (split-half method) to divide participants into restrained and non-restrained eaters. Accordingly, the group of restrained eaters included men and women whose scores were above 2.0 and 2.6 points, respectively. The control group consisted of those whose average score was below this value.

Chewing behavior

The surface EMG method was used to characterize chewing behavior according to the protocol described earlier [21]. Before the chewing test, participants were attached with three pairs of disposable electrodes (size 11 × 34 mm, Fiab, Italy): in the center of the masseter muscle belly, in the projection of the anterior temporalis muscle, and on the underside of the chin in the area of the suprahyoid muscles. Due to technical difficulties and the presence of beards, the activity of the suprahyoid muscles was measured only in 100 out of 129 participants. The interelectrode distance was 20 mm. The grounding electrode was attached to the wrist of the left hand. Before conducting the measurement, contact resistance (≤ 40 k Ω) and the absence of restriction in the movement of the masticatory muscles were checked. The measurement was conducted using the "Neuro-MEP" device with a 4-channel amplifier (Neurosoft, Ivanovo, Russia), and the EMG curves were analyzed using the Neuro-MEP.NET software (version 4.2.6.5). As a result, the following parameters were determined: chewing time (s), number of chewing cycles (times), chewing frequency (sec⁻¹), chewing cycle time (ms), maximum and mean values of amplitude (the root mean square value of signal, μ V), and the value of the area amplitude (mV × sec). These parameters were also calculated for the initial, middle, and final phases of mastication, which corresponded to the first, second, and third thirds of the total masticatory duration.

Reliability analysis included assessment of intra-rater and test-retest reliability was performed and intraclass correlation coefficients (ICCs) were calculated as recommended earlier [24]. Time parameters of chewing determined by EMG had moderate reproducibility, as the ICCs for chewing time, chewing number, and chewing cycle time were 0.756, 0.715, and 0.700 respectively. The mean EMG amplitude potential of the masseter, temporalis, and suprahyoid muscles was reproduced with ICCs of 0.900, 0.922, and 0.940. The

moderate test-retest reliability of the EMG data was found. The ICCs for chewing time, chewing number, and chewing cycle time were found to be 0.735, 0.802, and 0.551. The ICCs for the activity of masseter, temporalis, and suprahyoid muscles were 0.728, 0.523, and 0.658 respectively.

Masseter muscle thickness

Masseter muscle thickness was determined using an HS40 ultrasound scanner (Samsung Medison Co. Ltd., South Korea) in B-mode, equipped with a linear transducer operating at a frequency of 5–12 MHz. Prior to measurement, participants were instructed to briefly clench their teeth to maximum voluntary tension to identify the center of the masseter muscle. Recordings were taken at rest, when the maxilla and mandible were covered and there was a distance of up to 2 mm between the teeth, and during maximal volitional clenching of the teeth. The measurement was performed by one of the researchers (D.B.) with extensive experience in ultrasound imaging.

Data analysis

The minimum sample size was estimated using an a priori power analysis conducted in the program G*Power 3 (version 3.1.9.2; Franz Faul, Kiel University, Germany). It was calculated that a minimum of 128 people (64 per group) is needed to find the average effect (Cohen’s d = 0.5) between two different groups. These calculations were obtained using a two-tailed t-test, 80 % statistical power, and a 5 % significance level. Statistical analysis of the data was conducted using the R-based Jamovi software (version 2.3; The Jamovi project, Sydney, Australia) with a significance level set at *p* < 0.05. The Shapiro — Wilk test was used to determine the type of data distribution, the chi-square

test was used when comparing groups by gender, and the Mann — Whitney *U*-test and *t*-test were used to compare groups by chewing parameters and muscle thickness, respectively. The Friedman’s test and the Durbin post-hoc test were used when comparing data of different phases of mastication. The data and figures were processed in a Microsoft Excel spreadsheet (version 2010).

RESULTS

Participant characterization

Based on the DEBQ_{Res} data obtained from 129 individuals, two groups of untrained participants were formed, with 62 and 67 individuals per group. The control and experimental groups included individuals whose values on the restrained scale were lower or higher than the median value for the entire sample (for men — 2.0, for women — 2.6 points), respectively. Participants categorized as control and restrained eaters had scores of 1.7 ± 0.5 and 3.1 ± 0.6 on the DEBQ_{Res}, respectively (Table 1). Restrained eating was associated with higher BMI (by 7 %) compared with control. Immediately before the study, subjective feelings of appetite (hunger and stomach fullness) were similar in the control and restrained eating groups. The average scores on the external scale of the DEBQ were 2.8 ± 0.7 and 3.1 ± 0.6 (*p* = 0.012) in the control and experimental groups, respectively. The average scores on the emotional scale of the DEBQ were 1.6 ± 0.6 and 2.2 ± 0.7 (*p* = 0.000) in the control and experimental groups, respectively.

All participants required 15–35 seconds and 20–40 chewing movements to achieve a swallowable consistency for the chewing test. The time parameters of chewing had close values in the initial and middle phases of the chewing, regardless of eating behavior (Fig. 1). The

Table 1. General characteristics of control and restrained eating groups (mean ± SD)

Group	DEBQ _{Res} (scores)	Male/female	Ages (years)	BMI (kg/m ²)	Appetite (mm)	
					Hunger	Fullness
Control	1.7 ± 0.5	22/40	31.7 ± 8.3	23.7 ± 4.0	47 ± 25	28 ± 19
ResEat	3.1 ± 0.6*	24/43	31.6 ± 8.2	25.3 ± 3.9*	44 ± 30	31 ± 17

Note: * — difference with the control group (*p* < 0.05), ResEat — the restrained eating group, DEBQ_{Res} — the restrained scale of the Dutch Eating Behavior Questionnaire, BMI — body mass index.

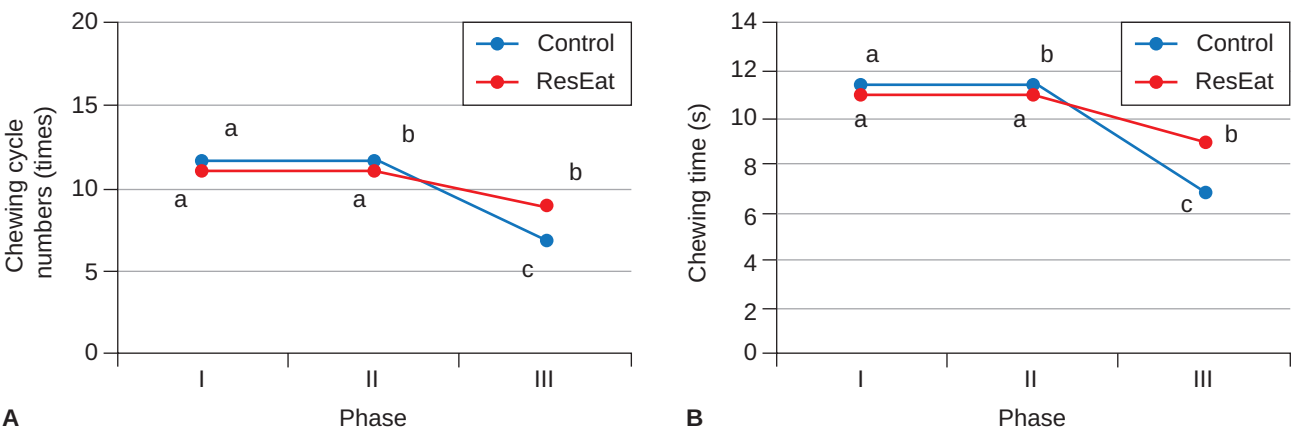


Fig. 1. Chewing cycle numbers (A) and chewing time (B) in initial (I), middle (II), and final (III) phases of chewing in control and restrained eating groups

Note: ResEat — the restrained eating group; means labelled with different lowercase letters (abc) indicate differences between phases (*p* < 0.05).

number of chewing cycles and chewing time was reduced in both groups by 50–60 % in the final phase, compared with the initial and middle phases of chewing.

The maximal and mean amplitudes of the masticatory muscle signal in restrained eaters were 17 % lower than in controls, despite the chewing cycle duration and frequency being similar (Table 2). Regardless of eating behavior, the maximal and mean amplitudes of the EMG signal of contraction of the temporalis muscle were 18–21 % and 15–17 % lower than those of the masseter muscle, respectively. The maximal amplitude of the suprahyoid muscle’s EMG signal showed no differences across groups (Table 2).

An analysis of the amplitude parameters of chewing during the three phases of chewing revealed that in restrained eaters, the maximal amplitude of the masseter muscle signal was reduced only in the initial phase of the chewing, while it did not differ from the control in the middle and final phases (Fig. 2A). The restrained eaters had a lower mean amplitude of the masseter muscle signal in the initial and middle phases of chewing than the control group (Fig. 2B).

Analysis of temporalis muscle activity showed that the maximal EMG signal amplitude in the initial phase of chewing was 25 % lower in restrained eaters, although the mean amplitude calculated for the entire chewing period did not differ between groups (Fig. 3A). There were no differences in the mean and area amplitudes of the temporalis muscle between restrained eaters and controls (Fig. 3B and C).

Analysis of the activity during the three phases of chewing revealed that the amplitude parameters of the suprahyoid muscle signal in the final phase were higher than in the initial and middle phases of chewing (Fig. 4).

At the same time, the mean signal amplitude in the final phase of chewing in restrained eaters was 15 % lower than in the control (Fig. 4B).

The thickness of the masseter muscle on the right and left sides was measured using ultrasound. The mean thickness of the right and left masseter muscles was 1.3–1.34 cm at rest regardless of eating behavior (Fig. 5). Volitional jaw clenching increased the thickness of the right and left muscles by 22–23 % in both the control and restrained eating groups.

DISCUSSION

The restraint hypothesis maintains that overeating is the result of attempting to restrict food intake in order to reduce weight below one’s natural weight. Attempts at restraint ultimately break down and lead to disinhibited eating [25, 26]. Numerous studies have shown that overeating among dieters can occur in conditions of disinhibition, for example, when they experience negative emotions or stress [16, 27]. Therefore, our first suggestion was that dieters’ restrained eating behavior would impact their chewing rhythm due to known changes in cognitive functioning, emotional state, and food reactivity. However, the results obtained showed that the chewing rhythm of restrained eaters is the same as that of those who do not restrict their diet.

The results obtained supported the second hypothesis that restrained eating is associated with decreased activity of masticatory muscles during chewing. During the chewing test, we noticed lower electrical activity of the masticatory muscles in restrained eaters, specifically the masseter and suprahyoid muscles. Similar observations were made by

Table 2. Temporal and amplitude electromyographic parameters during chewing in control and restrained eating groups (mean ± SD)

Parameter	Control	ResEat
Chewing cycle number (times)	35.0 ± 18.2	31.9 ± 10.6
Chewing time (sec)	24.2 ± 12.1	23.2 ± 8.8
Chewing frequency (sec⁻¹)	1.44 ± 0.25	1.40 ± 0.28
Chewing cycle time (ms)	714 ± 133	747 ± 166
Masseter muscle		
Maximal amplitude (μV)	1156 ± 790	955 ± 742*
Mean amplitude (μV)	41 ± 24	34 ± 24*
Area amplitude (mV · sec)	1057 ± 759	857 ± 795
Temporalis muscle		
Maximal amplitude (μV)	912 ± 542	783 ± 514
Mean amplitude (μV)	34 ± 19	29 ± 17
Area amplitude (mV · sec)	904 ± 670	734 ± 518
Suprahyoid muscles		
Maximal amplitude (μV)	899 ± 422	781 ± 417
Mean amplitude (μV)	40 ± 15	33 ± 15*
Area amplitude (mV · sec)	1101 ± 693	887 ± 508

Note: * — difference with the control group ($p < 0.05$), for suprahyoid muscles data $n = 49$ and 51 in the control and restrained eating group, respectively, ResEat — the restrained eating group.

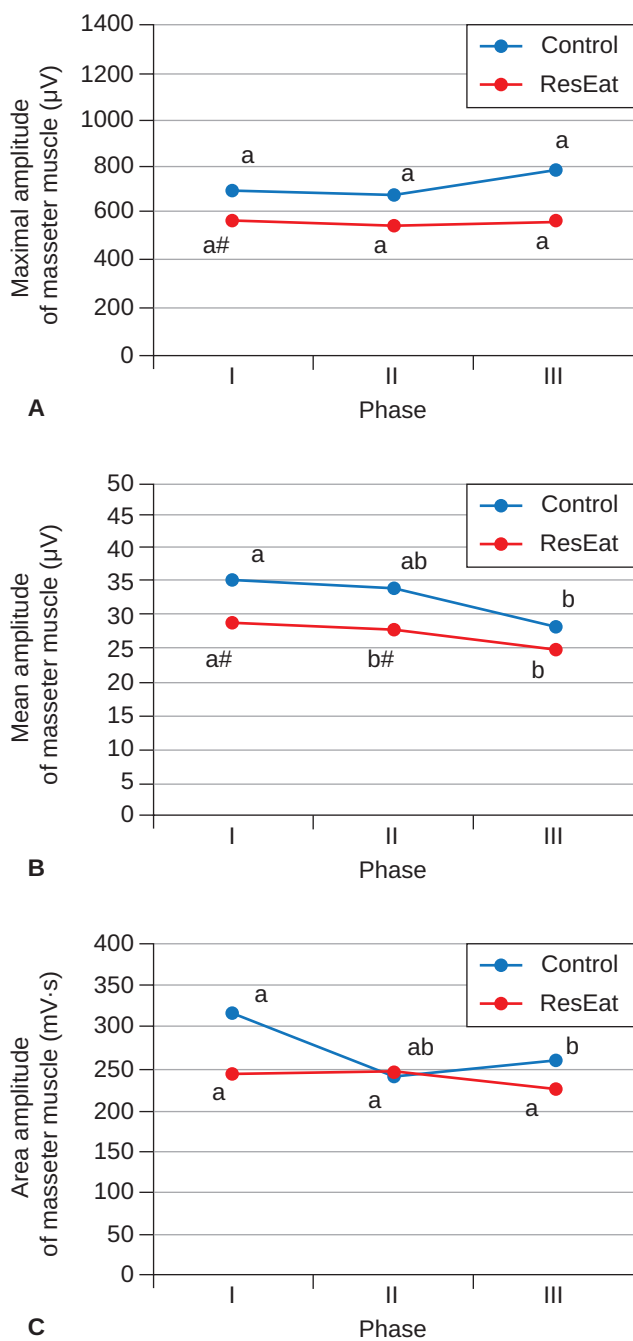


Fig. 2. Maximal (A), mean (B), and area (C) amplitude electromyographic signal of masseter muscle in initial (I), middle (II), and final (III) phases of chewing in control and restrained eating groups

Note: ResEat — the restrained eating group; means labelled with different lowercase letters (abc) indicate differences between phases ($p < 0.05$); means labelled with # indicate a difference with the control group ($p < 0.05$).

Regalo I.H. [28] in a study of chewing in obese people and Park S. [29] in a study of the relationship between chewing parameters and the severity of disinhibited eating. It is important to note that the amplitude of the EMG signal of the masseter and temporalis muscles decreases in restrained eaters in the initial phase of chewing. Reduced muscular activity at the start of chewing may result in worse grinding of food and a decrease in the bioavailability of nutrients and flavor compounds. As a result, the loss of food value and taste sensations may cause a transition from self-restraint in food intake to a time of overeating with new intensive

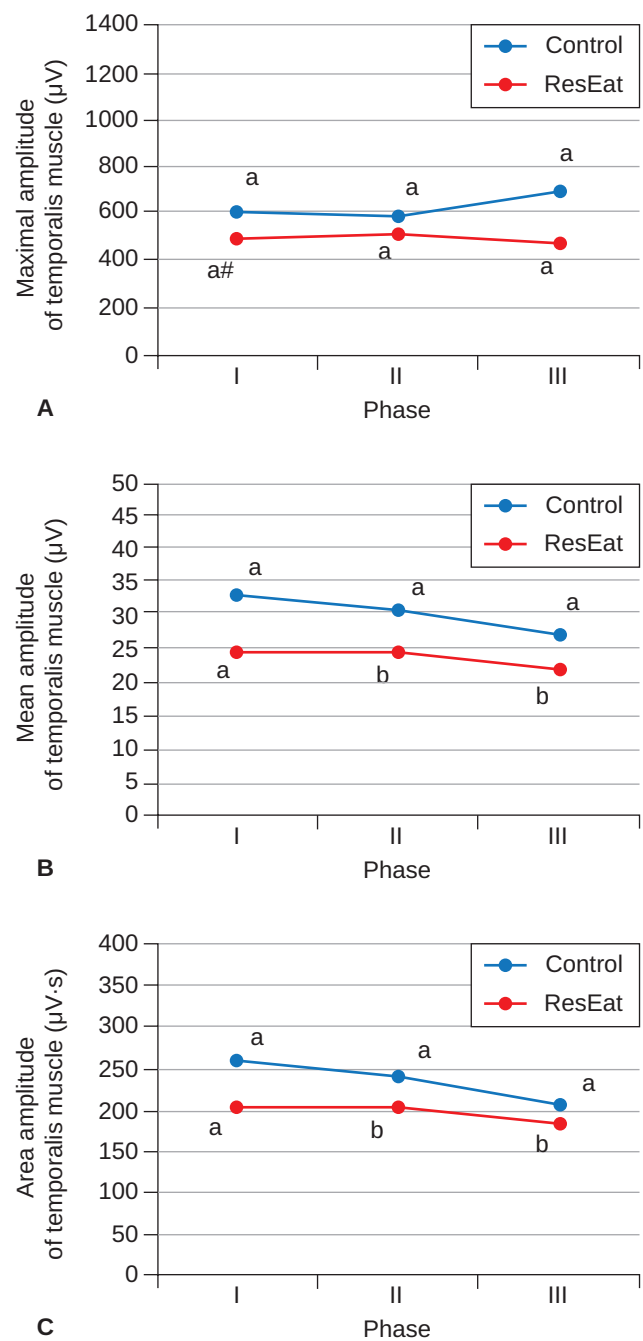


Fig. 3. Maximal (A), mean (B), and area (C) amplitude electromyographic signal of temporalis muscle in the initial (I), middle (II), and final (III) phases of chewing in control and restrained eating groups

Note: ResEat — the restrained eating group; means labelled with different lowercase letters (abc) indicate differences between phases ($p < 0.05$); means labelled with # indicate a difference with the control group ($p < 0.05$).

weight gain in restrained eaters. A decrease in chewing activity at the final stages of chewing food can affect the physicochemical properties of the forming bolus. In turn, the physicochemical properties of the bolus largely determine the efficiency of its digestion in the gastrointestinal tract.

Limitations

The study had the following limitations. Firstly, median grouping results in less pronounced differences between clusters compared to, for example, tertile grouping (1.4 vs. 1.9 score on the DEBQ_{Res}, respectively). There is

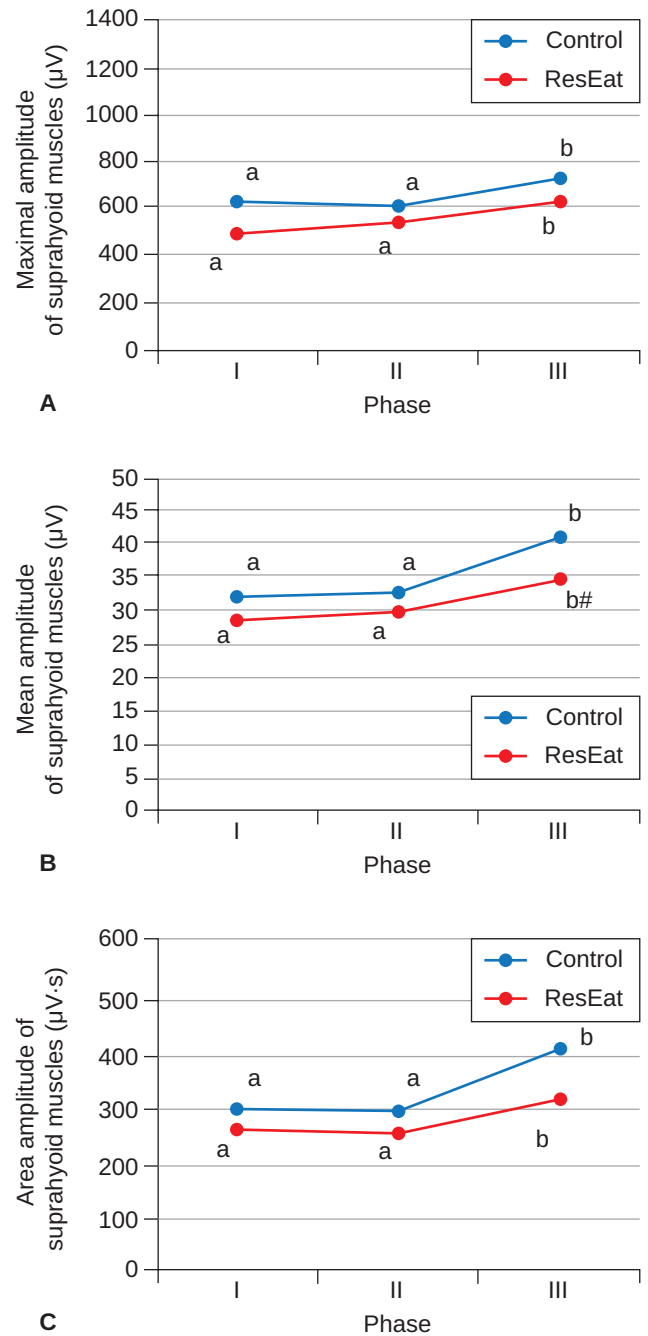


Fig. 4. Maximal (A), mean (B), and area (C) amplitude electromyographic signal of suprahyoid muscles in the initial (I), middle (II), and final (III) phases of chewing in control and restrained eating groups

Note: ResEat — the restrained eating group; means labelled with different lowercase letters (abc) indicate differences between phases ($p < 0.05$); means labelled with # indicate a difference with the control group ($p < 0.05$).

ADDITIONAL INFORMATION

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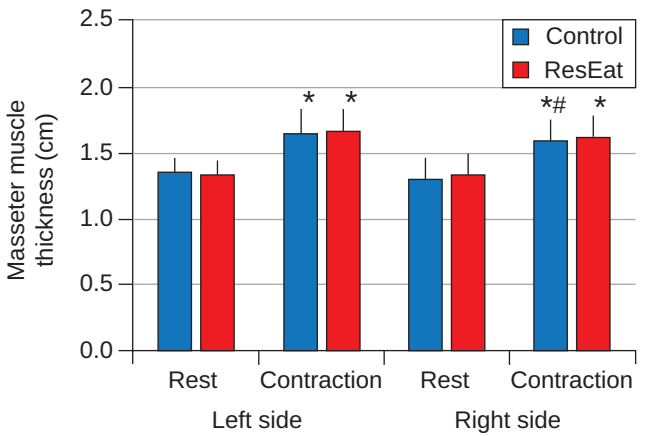


Fig. 5. Masseter muscle thickness in control and restrained eating groups (mean $\pm$ SD)

Note: ResEat — the restrained eating group; means labelled with * and # indicate differences with rest and the left side, respectively ($p < 0.05$); no differences were found between control and restrained eating groups ($p > 0.05$); $n = 26$ in each group.

a possibility of making a type II error with such a method of grouping. Second, the dependence of chewing function and eating behavior on gender, age, and BMI imposes significant limitations on the interpretation of data that should be taken into account in future cohort studies. Third, it is important to note that the homogeneous agar gel used in chewing tests was different from natural food products with a complex structure that directs the chewing process.

CONCLUSION

Thus, restrained eaters demonstrated reduced masticatory muscle activation in the chewing test. The activity of the masseter and temporalis muscles was reduced in the initial phases of chewing, whereas the activity of the suprahyoid muscles was reduced in the final phase of bolus formation and swallowing. Restrained eating behavior did not appear to influence chewing timing. The data showed that the chewing function's characteristics might have a role in the risk of overeating and individual differences in eating behavior. Decreased masticatory muscle activity should most likely be seen as a negative factor, since it may reduce the efficacy of oral meal processing and, as a result, nutritional availability. It is advisable to identify restrained eating behavior and assess chewing function when prescribing calorie-restricted dietary therapy to patients in health resort treatments. Medical rehabilitation of patients with restrained eating behavior should include the use of treatment technologies aimed at restoring the activity of the masticatory muscles.

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