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Assessment of the differences in masticatory behavior between male and female adolescents

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HIGHLIGHTS

- The results support the existence of sex differences in masticatory behavior.
- Eating fast does not necessarily imply worse masticatory performance.
- The results may help the assessment of sex-specific treatment outcomes.
- Normative data may be useful when considering different populations and conditions.

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ABSTRACT

Chewing behavior may show sex differences; thus, the present study aimed to compare the masticatory aspects and the prediction of masticatory performance between male and female adolescents. Ninety-one healthy subjects (47 girls, 44 boys), caries-free and aged 14–17 years, were included. Masticatory performance and maximal bite force were evaluated using a color-changeable chewing gum and digital gnathodynamometer, respectively. Masticatory behavior was assessed by the subjective aspect of the quality of the masticatory function (validated questionnaire) and the Orofacial Myofunctional Evaluation with Scores expanded (OMES-e) was used to determine chewing time, frequency of chewing cycles and other aspects. Salivary flow rate was also assessed. The physical examination involved measurements of facial morphometry, body weight, height, skeletal muscle mass, and dental/occlusal evaluations. It was observed that boys showed larger facial dimensions, higher bite force and chewing frequency and better masticatory performance than girls. They also showed shorter chewing time, fewer chewing cycles and lower score for OMES-e (that is, more changes in orofacial myofunctional aspects). Bite force showed a weak correlation with skeletal muscle mass only in boys ($r = 0.3035$; $p = 0.0451$). The masticatory performance was dependent on the bite force in boys (Adj $R^2 = 19.2\%$; Power = 84.1%); among girls, masticatory performance was dependent on the frequency of chewing cycles and masticatory behavior (subjective aspect) (Adj $R^2 = 34.1\%$; Power = 96.1%). The findings support the existence of sex differences in many masticatory aspects of function and behavior, hence the importance of considering sex differences when evaluating masticatory function and myofunctional therapy outcomes among young subjects.

1. Introduction

Chewing is one of the most important functions of the stomatognathic system and it is meant to reduce the size of food particles to prepare them for swallowing and digestion [52]. Biting and chewing food is a multisensory task that requires a high level of coordination of all structures of the mouth. During chewing, the sensory contact with food stimulates saliva production and satiety signals are transmitted to the brain, which are triggered by gastric distension and the release of gut factors, including cholecystokinin [32], preparing the organism to assimilate the ingested nutrients [43]. At the same time, it involves enjoyable sensations related to taste and the pleasure of eating [41].

The reduction of food particles is determined by a complex multifactorial process, which depends on the force of masticatory muscles (bite

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force) and their coordination, the craniofacial morphology and the number of occluding pairs of teeth, once they comprise the occlusal area where food is fragmented [52]. The properties of the food being chewed, in terms of hardness, fat content, food portion size and food structure, are also important [5], as the number of chewing cycles increases with food hardness [19] and decreases with the fat content of the food [11].

Masticatory function may be evaluated by objective and subjective measures. Whereas objective measures such as masticatory performance and efficiency and evaluation of bite force can provide specific and reliable values of the masticatory process, questionnaires may help to understand an individual's chewing behavior and diagnose any difficulties while performing the function [20,21,28]. Using a validated questionnaire, it is possible to assess if the subject avoids a certain type of food because of its size or consistency.

Males and females may show differences in some aspects of their feeding and masticatory behavior. With regard the comparison of masticatory movements' path and rhythm, Tamura and Shiga [50]) reported differences for spatial (vertical and lateral movements) and temporal parameters (opening, closing, occluding and cycle times) between male and female adults. Sex differences for maximal bite force were also previously found in adults [39,47]; in young subjects, this issue has not been properly explored, and the few previous studies found did not evaluate the interrelationship between masticatory performance and chewing behavior [6,53].

The understanding of the mechanisms involved in the masticatory function allows health professionals to act on the prevention and treatment of eating disorders and facial and dental impairments. The hypothesis to be tested was whether masticatory parameters and chewing behavior may show sex differences in healthy adolescents. Therefore, the purpose of this study was to compare the masticatory behavior and the prediction of masticatory performance between male and female adolescents.

2. Materials and methods

2.1. Sample selection

The reporting of this research follows the STROBE recommendations for reports of observational studies [29]. This study was approved by the Ethics Committee of the School of Dentistry of Piracicaba (protocol n. 152/2014), Brazil. The procedures and possible discomforts or risks were fully explained to the adolescent and their parents/guardians. Each subject and his parent/guardian gave voluntary consent to participate in this research by signing an informed assent form and a parental/guardian consent form, respectively, after having their questions and concerns addressed.

Approximately 1435 students aged 14–17 years of five Public Schools of Piracicaba were invited to participate in this study. Only 337 agreed to participate: 217 were excluded from the eligibility criteria, 29 left the school in the middle of the survey and the final sample consisted of 91 adolescents (47 girls and 44 boys) of three schools located in the downtown area and two schools located on the outskirts of the city. Sample size calculation was based on results from a previous study of our group which evaluated the relationship between bite force, sex, skeletal muscle mass and other independent variables in children [2]; considering a regression coefficient equal to 3.379, power = 0.80, and alpha level of 0.05, it was found that 88 subjects (44 subjects of each sex) would be necessary to perform such evaluation. All evaluations were conducted in classrooms or in school libraries during the year 2015.

2.2. Anamnesis and oral examination

Anamnesis consisted of an interview with the adolescent to assess the demographic data (personal data, self-reported ethnicity: white or Afro-Brazilian), dental and medical experiences, presence of parafunctional habits (finger sucking, nail biting, sleep bruxism, mouth breathing, snoring, asthma and bronchitis); history of orthodontic treatment and chronic use of medications or drugs [2,34]. This information was useful to check the homogeneity of the sample and exclusion criteria.

The dental health status was evaluated using the DMFT index (total of decayed, missing and filled teeth), following the World Health Organization criteria, by a calibrated examiner (DSA) [55]. The presence of periodontal pockets was recorded according to the Community Periodontal Index [55], and the index teeth were: 11, 31, 16, 26, 36, 46.

The presence of symptoms of temporomandibular dysfunction (TMD) was screened as proposed by the American Academy of Orofacial Pain [10]. The questionnaire consisted of 10 questions that individually asked about temporomandibular joint (TMJ) sounds and pain, masticatory muscle pain or fatigue of the jaw and difficulty during mouth opening, which ultimately could interfere in the masticatory function. As previously proposed by Gonçalves et al. [13]), the subjects who reported the presence of pain were excluded.

Finally, the inclusion criteria for this convenience sample were: adolescents with permanent dentition (excluding third molars) and those presenting normal weight classified according to the BMI-for-age and sex reference data (5–19 years) [54]. Subjects were excluded based on the following criteria: (1) self-report of muscle/TMJ pain, (2) history of previous orthodontic treatment, (3) presence of teeth decay and/or missing teeth, (4) dental origin, (5) periodontal pockets (>3 mm), (6) subjects classified as underweight, overweight and obesity, (7) presence of chronic diseases/conditions such as neurological or cognitive deficit, (8) previous or current tumors or traumas, (9) complains of xerostomia and (10) current use of analgesic, anti-inflammatory and psychiatric drugs.

2.3. Anthropometric evaluations

Anthropometric evaluation included the measurements of weight, height and body mass index (BMI = kg/m^2). In addition, the body skeletal muscle mass was measured using Bioelectric Impedance (InBody 230, Biospace Co. Ltd., Gangnan-gu, Seul, South Korea). The InBody 230 is a segmental impedance device, which uses a tetrapolar 8-point tactile electrode method. During impedance measurements, the participants were in a normal standing position with the arms and legs extended, in accordance with the manufacturer's instructions. The subjects removed their shoes and socks and wore light clothing. Moreover, the analyses were performed in the morning, without subjects having done exercise or eaten before this (at least 2 h after the last meal).

The facial anthropometry examination was performed using a sliding caliper (Bone Caliper in 240 mm aluminum, Cescorf, Brazil). For each volunteer, seven craniometric points were determined (Fig. 1), located by palpation/inspection and marked directly on the skin using an eyeliner. All subjects were seated in a relaxed position, with the Frankfort plane horizontal to the floor and teeth in the intercuspal position [14,23].

The distances: *nasion-gnathion*, *subnasale-gnathion*, *zigion-zigion* and *gonion-gonion* were evaluated in millimeters, considering the following landmarks: the *nasion* is the most anterior point of the fronto-nasal outline in the midline; *gnathion* is the most anterior and inferior point of the bony chin; *subnasale* is where the lower margin of the nasal septum is confluent with the intergumental upper lip; *zygion* is the most lateral point on the zygomatic arch; and *gonion* is the lowest posterior and outward point of the angle of the mandible.

2.4. Peer assessment rating (PAR) index

The assessment of the severity of malocclusion was performed using the Peer Assessment Rating (PAR) index, which was based on the sum

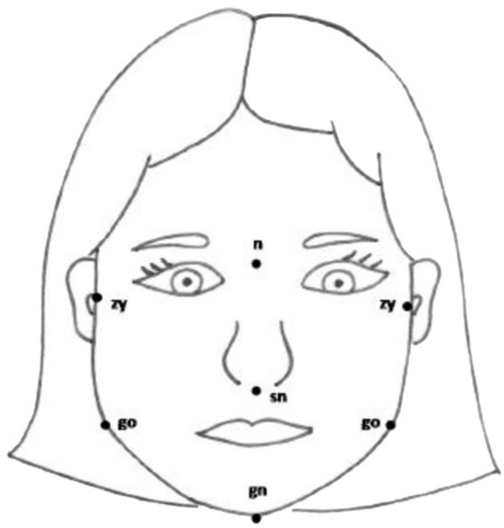

Fig. 1. Craniometric points adopted: n, *nasion*; zy, *zygion*; go, *gonion*; sn, *subnasale*; gn, *gnathion*.

of 11 weighted components of malocclusion including posterior right, posterior left and anterior tooth displacement (maxillary and mandibular), right and left buccal occlusion, overjet, overbite, and midline discrepancy [44]. The assessments were made directly on the patient's mouth, using a mirror and millimetric periodontal probe. The records were performed by the first author (KGOS), after proper training and calibration.

2.5. Masticatory performance

Masticatory performance was evaluated by a colorimetric method, which uses a color-changeable chewing gum specifically designed for this purpose (Masticatory Performance Evaluating Gum Xylitol, Lotte, Tokio, Japan). The gum base contains red, yellow and blue dyes, citric acid and xylitol. The initial color of the gum is green because the red color is inhibited by citric acid. When the chewing gum is mixed with saliva as mastication proceeds, the pH inside the chewing gum increases because of the excretion of citric acid in the saliva and, at the same time, the elution of the yellow and blue pigments changes the color of the chewing gum from yellowish-green to red. This methodology has the advantage of using a widely consumed "food" by adolescents, easily accepted and with pleasant taste [16,31].

The subjects were instructed to chew the gum for one minute as usual ("Please chew the gum well") and the time was measured with a chronometer. Then, the chewed gum extracted immediately after chewing was compressed between two plastic films and pressed into an approximately 30-mm diameter disk. As visual measurement for quantifying color is a subjective attribute, two examiners performed the evaluation (APP and DSA), who were trained with both methods: color scale and reflectance spectrophotomer. A spectrophotometer (Konica Minolta CM-700d-Konica Minolta Investment Ltd. Sensing

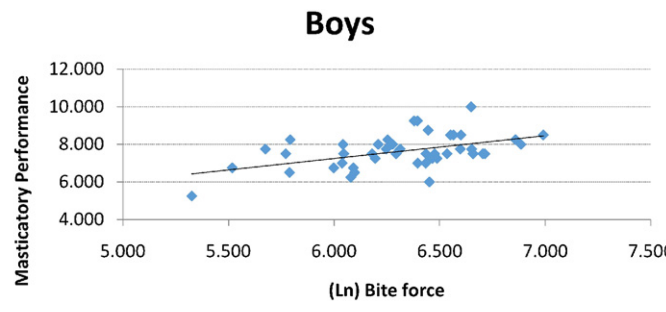

Fig. 3. Prediction of masticatory performance in boys (Adjusted $R^2 = 0.192$). Ln, logarithmic transformation.

Business Division, Shanghai, China) was used to measure the color of the gum based on the CIE L*a*b* color space system; the Spearman correlation coefficient obtained between spectrophotomer and examiner 1 (APP) was 0.84 ($p = 0.0006$) and the correlation coefficient between spectrophotomer and examiner 2 (DSA) was 0.92 ($p < 0.0001$). After this, all chewed gums were evaluated using the color scale (Fig. 2); the evaluation was repeated twice, and the average of the measurements was considered as the final value.

2.6. Maximal bite force

Maximal bite force was evaluated using a digital gnathodynamometer (Dinamômetro Digital Kratos model DDK, Kratos Equipamentos Industriais Ltda., Cotia, Brazil), with fork strength of 10 mm connected to a digital device which provided the unilateral bite force in Newton (N). The fork was placed bilaterally over the first permanent molars, and the recordings were performed twice, with an interval of 1 min. During the test, subjects were seated in an upright position with the head in a natural position, keeping the Frankfort plane parallel to the floor. Before the recordings, each adolescent was instructed to bite the fork as forceful as possible. The maximum value measured was defined as the maximum bite force.

2.7. Quality of masticatory function questionnaire

The subjective aspect of the quality of the masticatory function was evaluated using the self-applied instrument (Quality of Masticatory Function Questionnaire - QMFQ), which consisted of 26 questions related to the frequency and intensity of the difficulty in chewing different types of food during the two weeks before the evaluation. This questionnaire was translated to Portuguese, adapted and validated previously [20,21], and the English version was also previously showed [33].

The questions are distributed in five domains: Food-Mastication, Habits, Meats, Fruit and Vegetables, and they explore the difficulty with mastication in the daily life. The following are examples of these questions:

Fig. 2. Color scale specifically designed for the evaluation of changes in the color of the chewing gum from yellowish-green to red.

Table 1
Measurements of reproducibility for the variables evaluated in the pilot study.

Variables	n	Test	Values
DMFT	20	Kappa	0.97
PAR	15	Intraclass Correlation	0.48
OMES-e	15	Intraclass Correlation	0.86
Bite Force	15	Intraclass Correlation	0.97
MP - examiner 1	12	Intraclass Correlation	0.66
MP - examiner 2	12	Intraclass Correlation	0.78
MP - between examiners 1 and 2	12	Intraclass Correlation	0.90

DMFT, index of decayed missing and filled permanent teeth; PAR, Peer Assessment Rating index; OMES-e, orofacial myofunctional evaluation with scores-expanded; MP, masticatory performance.

- Do you have difficulty chewing hard, raw fruits, without cutting them (e.g.: apples)?
- Do you have to drink while eating to facilitate swallowing?
- In general, is the food well chewed before being swallowed?

All of the questions have 5 *Likert*-answers options ranging from “always” to “never” or “a lot” to “no difficulty”. Furthermore, the domains Meats, Fruits and Vegetables also present an alternative to be checked (not applicable - N/A) if the subject does not usually eat these foods. The higher the score is, the worse the quality of mastication.

2.8. Orofacial myofunctional evaluation with scores-expanded (OMES-e)

This evaluation was performed using the protocol Orofacial Myofunctional Evaluation with Scores-expanded (OMES-e), validated for young and adult subjects, which allows clinical evaluation of orofacial structures and their functions [12]. This evaluation was recorded using a camera (Nikon Coolpix L810, São Paulo-SP, Brazil) at a standardized distance (1 m) from the subject, fixed on a tripod with focus on the face, neck and shoulders. During recording, the subject remained sitting in a chair with backrest and the feet resting on the floor.

This protocol evaluates the aspects of Posture/appearance, Mobility and Functions attributing scores to each evaluated variable; among the functions, the “Mastication” domain explores the following aspects: the type of bite (incisors, canines, posterior teeth or do not bite), chewing side preference (unilateral, bilateral or alternate), posture alterations (head/body or food escape), total number of masticatory cycles and chewing time, with a total score ranging from 5 to 20. These evaluations were performed by one trained examiner (DGAP; Speech-Language Pathologist, PhD in Oral Physiology). The subjects were instructed to chew a chocolate flavored sandwich cookie (Bono®, Nestlé, Brazil) in their habitual manner and the total time spent to consume it was measured with a digital chronometer, which was started after the food was placed in the oral cavity and stopped after the final deglutition of the cookie. The total time of mastication and the number of strokes were considered, as well as the chewing frequency (cycles/min).

2.9. Salivary flow rate

Stimulated saliva was collected in the morning, with all subjects having refrained from eating or drinking for a minimum of 2 h before collection. It was collected from subjects chewing on 0.3 g of an inert and tasteless material (Parafilm, Merifeld, USA), for approximately 70 cycles/min and spitting all the saliva produced for 5 min. into a pre-weighed container. Salivary flow rate was estimated as the volume of saliva secreted per min (ml/min).

Table 2
Sample characteristics according to ethnicity, age, malocclusion index, body mass index (BMI), skeletal muscle mass and facial morphology (cm).

(n)	Ethnicity (n)	Age (y)	BMI (kg/m^2)	PAR index	Skeletal muscle mass/weight ratio	n-gn	sn-gn	zy-zy	go-go	n-gn/zy-zy ratio
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Median (25–75%)	Mean (SD)	Median (25–75%)	Mean (SD)	Mean (SD)
Girls (47)	Afro-Brazilian (16) Caucasian (31)	15.78 (0.97)	20.09 (1.81)	7.94 (7.48)	0.40* (0.03)	12.00*** (11.65–12.40)	5.94** (0.38)	12.50*** (12.10–12.85)	10.11* (0.62)	0.97 (0.06)
Boys (44)	Afro-Brazilian (22) Caucasian (22)	15.92 (1.05)	19.79 (2.19)	9.57 (8.29)	0.48* (0.03)	12.80*** (12.25–13.20)	6.44** (0.42)	13.00*** (12.48–13.50)	10.44* (0.56)	0.98 (0.06)

SD, standard deviation; PAR, Peer Assessment Rating index; n-gn, nasion-gnathion; sn-gn, subnasale-gnathion; zy-zy, zigion-zigion; go-go, gonion-gonion.
* $p < 0.05$ (unpaired *t*-test).
** $p < 0.0001$ (unpaired *t*-test).
*** $p < 0.001$ (Mann-Whitney test).

2.10. Statistical analysis

Statistical analyses were performed using the statistical software packages BioEstat 5.3 (Mamirauá, Belém, PA, Brazil) and SigmaPlot 13 (Systat Software Inc., San Jose, CA, USA). A p-value ≤ 0.05 was considered significant.

A pilot study was conducted before beginning the data collection to verify the reproducibility of the measurements made and later calculation of agreement (Kappa test) and intraclass correlation coefficient (ICC).

The characteristics of the studied variables were evaluated using descriptive statistics (means and standard deviations or medians and interquartile ranges) and percentages; normality tests were used to verify the distribution of the variables. Comparisons between males and females were performed using unpaired *t*-test or Mann-Whitney test. The correlation between maximal bite force and skeletal muscle mass/total weight was assessed by means of Pearson correlation. Proportions were tested using Chi-square test.

To evaluate which of the variables under study contributed to the variation in masticatory performance, a multiple linear regression model with backward stepwise elimination was used for each sex. The stepwise procedure was employed to choose the model with the highest adjusted R-square and the variance inflation factor (VIF) at or near 1.0. Based on biological plausibility and to prevent the multicollinearity problem, the following independent variables were added to the initial model: age, bite force, PAR index, facial proportion (n-gn/zy-zy), skeletal muscle mass/body weight, scores on the Quality of Masticatory Function questionnaire, total score on OMES-e, chewing frequency and salivary flow rate. The independent variables were thus eliminated step-by-step until those that attained a p-value ≤ 0.05 remained in the final model.

3. Results

Table 1 shows the measures of reproducibility obtained in the pilot study. The intra-examiner reproducibility found ranged from satisfactory (PAR index) to excellent reproducibility (DMFT).

The characteristics of the sample divided by sex are shown in Table 2. There were no significant differences between boys and girls in the following aspects: ethnicity, age, PAR index and BMI.

The skeletal muscle mass/body weight ratio showed a statistically significant difference between males and females, with boys presenting greater muscle mass in relation to total body weight than girls. In addition, boys presented larger craniofacial dimensions, although the mean facial proportion (n-gn/zy-zy) did not differ from females in this sample.

The description and comparisons of the masticatory aspects between males and females are shown in Table 3. According to the results found, boys showed higher bite force, better masticatory performance and more chewing cycles/min than girls. On the other hand, boys showed shorter total chewing time, fewer chewing strokes and lower scores on OMES-e protocol, that is, more changes in the orofacial myofunctional status. The salivary flow rate did not differ between girls and boys.

The correlation coefficients found between maximal bite force and skeletal muscle mass/body weight were $r = 0.3035$ ($p = 0.0451$) and $r = -0.0281$ ($p = 0.8514$) for boys and girls, respectively.

Table 4 shows the scores obtained in each domain of the Quality of Masticatory Function Questionnaire; according to results found, there were no significant differences between girls and boys in any domain.

Table 5 shows the linear regression models obtained for each sex in the prediction of masticatory performance. Among girls, chewing frequency and the scores on the quality of masticatory function questionnaire significantly contributed to the variance in masticatory performance. The equation used was: *Masticatory performance* = *5.758–0.455* (ln) *Scores on the quality of masticatory function questionnaire* + *0.045 Masticatory cycles/min*.

In boys, masticatory performance was dependent on bite force (Fig. 3). The equation used was: *Masticatory performance* = *0.226* + *1.184* (ln) *Bite force*.

4. Discussion

Currently, some new validated and reproducible methods for the evaluation of the aspects of mastication have been proposed, and they are useful to better understand the masticatory process, the differences between the subjects' characteristics, for the early diagnosis of impairments and to evaluate treatment outcomes [26]. In past studies, the degree of food fragmentation was evaluated using natural food, e.g. peanut, almond and pistachio [42], or test-material such as Optocal [30]. Although a synthetic material has shown reliable results, the sieving of fragmented particles has shown to be complex and time-consuming [28]. Natural foods have the advantage of being well accepted and having a more pleasant taste and texture; chewing gum also has the advantage of being routinely consumed by young individuals [31].

According to previous findings, females usually take longer to chew until swallowing the bolus [39], taking smaller bites during mastication. Moreover, Neill and Howell [35]) observed that women presented greater cycle time because of a longer pause during interocclusal contact, corroborating our results that showed greater chewing time among girls. Differences in electromyographic activities during mastication and vertical amplitudes were also found in the literature, with males showing greater vertical amplitude and higher EMG activity per sequence than women [42].

Boys achieved lower scores on the orofacial myofunctional evaluation, which included the assessment of many aspects of masticatory behavior such as the type of bite, preference of chewing side and posture alterations [12]. The orofacial myofunctional disorder is defined as any pattern involving oral and/or orofacial musculature that interferes with normal growth, development or function of structures, or that calls attention to itself [3]. Boys also showed decreased chewing time and fewer chewing strokes than girls, corroborating previous studies [25,39], even though they showed better masticatory performance. A

Table 3
Sex comparisons in orofacial myofunctional evaluation with scores-expanded (OMES-e), bite force (N), masticatory performance, chewing time (sec), strokes and frequency and salivary flow rate.

	Bite force	Masticatory performance	OMES-e scores	Chewing time	Chewing strokes	Masticatory cycles/min	Salivary flow rate (mL/min)
	Mean (SD)	Mean (SD)	Median (25–75%)	Mean (SD)	Median (25–75%)	Mean (SD)	Mean (SD)
Girls (47)	394.78** (162.45)	7.19* (1.00)	20.00**** (16.00–20.00)	48.77** (12.96)	48.00*** (41.50–55.00)	61.82* (12.31)	1.20 (0.60)
Boys (44)	582.79** (194.72)	7.62* (0.89)	16.00**** (15.00–17.00)	38.73** (10.26)	41.00*** (34.75–45.25)	66.63* (14.01)	1.41 (0.73)

SD, standard deviation.
* $p < 0.05$ (unpaired *t*-test).
** $p < 0.0001$ (unpaired *t*-test).
*** $p < 0.001$ (Mann-Whitney test).
**** $p < 0.05$ (Mann-Whitney test).

Table 4
Quality of Masticatory Function Questionnaire: sex comparisons.

	Food-mastication	Habits	Meat	Fruits	Vegetables
Median (25–75%)					
Girls	2.0 (0.0–5.0)	4.0 (2.0–5.0)	1.0 (0.0–4.0)	1.0 (0.0–4.0)	3.0 (0.0–5.0)
Boys	1.0 (0.0–4.0)	3.5 (2.0–4.25)	2.0 (0.0–4.0)	1.0 (0.0–3.25)	3.0 (2.0–4.0)

$p > 0.05$ (Mann-Whitney test).

number of studies have reported that eating fast has been associated with decreased satiety, increased total energy intake, insulin resistance and obesity [15,36,37,46] because of the poorer masticatory performance [45]. The present results show that this aspect should be better examined and understood as eating fast does not necessarily mean worse performance if the generated muscle force and the number of chewing cycles are appropriate.

Hatch et al. [17]) did not find sex differences in masticatory performance in adults, although the authors have included subjects with diverse occlusal conditions, thus compromising the results found. In the study of Shiga et al. [47]), masticatory performance was evaluated by chewing a gummy jelly, extracting and measuring the amount of glucose present in saliva; their results are in accordance with our findings, with the amount of glucose extracted being significantly higher for males.

Corroborating past studies [4,47,53], boys showed higher bite force than girls. It is believed that sex-related differences become significant during the post-pubertal period, when the development of muscle mass occurs under the influence of androgenic steroids in males [6]. In addition, the masseter muscles of males have type II fibers with larger diameter and sectional area than those of females, thus suggesting that hormonal differences in males and females can be responsible for the composition of muscle fibers [27,51]. Probably, this is the reason why bite force showed significant correlation with body skeletal muscle mass only in boys. In pre-pubertal children, a past study observed a strong correlation between bite force and body skeletal muscle mass when considering boys and girls together [2]. This difference may be due to two hypotheses: from adolescence to adulthood, factors other than genetics may influence the body muscle mass, such as physical exercises (sports and fitness), which may not have an effect on the composition and strength of masticatory muscles. Moreover, the functioning of the masticatory muscles may be subject to other influencing factors such as diet, consistency of food ingested and dentofacial morphology during growth and development [41,49].

As boys also showed higher bite force, we hypothesized that they may compensate for the decreased chewing time and oro-facial myofunctional alterations using a more powerful bite force and higher chewing frequency. The regression analysis showed that bite force was the aspect that most contributed to the variation in masticatory performance, among the studied variables included. Among girls, masticatory performance was dependent on the subjective aspects of the quality of mastication and chewing frequency. The Quality of Masticatory Function Questionnaire is specifically related to the frequency of and difficulty with mastication of foods of different consistencies, besides accessing eating habits such as “drinking while eating” and “considering the food well chewed before being swallowed” [20]. Although no significant sex difference was observed, the subjective evaluation of the quality of the masticatory function was consistently related with masticatory performance among girls. This finding shows that their habits and attitudes during meals and the perceived difficult with mastication were significantly related to the masticatory performance measured by a color-changeable chewing gum. Chewing frequency, that is, the number of chewing cycles per minute, also contributed to a better masticatory performance.

Saliva acts by lubricating and softening food particles into a bolus conducive to swallowing, thereby facilitating the gastrointestinal absorption of food particles [40]. A previous study [24] evaluated the relationship between masticatory performance and salivary flow rate in older adults. Interestingly, the authors observed that among the elderly who wore removable dentures the salivary flow was significantly related to masticatory performance, while in the dentate group a significant relationship was not observed, in agreement with our results. This suggests that alterations in salivary flow rate may impact the masticatory performance in advanced age, when a significant decrease in saliva secretion occurs and tooth losses are more frequent [24].

Larger facial measures were found among males when compared to females, corroborating past studies [34,56]. On average, facial proportion did not show sex-differences and, in addition, our results did not show significant association between facial morphology and masticatory performance in boys and girls. Despite the relation between bite force and facial morphology being extensively investigated in the past few years [4,7,48], few studies examined its influence on masticatory performance [22]. Hirose and Ito [22]) observed strong correlation between masticatory performance and dentofacial morphology in young adults.

Occlusal and dentofacial abnormalities, such as few occlusal contacts and large overjet, showed to be predictive factors for reduced masticatory efficiency in a previous study [18] and, in general, orthodontic treatment has shown to improve both masticatory performance and ability [1]. However, the present findings did not observe a relationship between occlusal characteristics and masticatory performance; a possible explanation may be the low score achieved by the adolescents in the PAR index, that is, they showed little deviation from normal occlusion. The PAR index was developed to be used on study models, instead of

Table 5
Multiple linear regression models of subject's variables on masticatory performance for girls and boys.

	Dependent variable: masticatory performance	Coefficient	p-value	Model		
				F (p-value)	Adjusted R^2	Power 5%
Girls	Constant	5.758	–	8.255 (0.002)	0.341	0.961
	(ln) scores on the quality of masticatory function questionnaire	−0.455	0.029			
	Masticatory cycles/min	0.045	0.002			
Boys	Constant	0.226	–	9.777 (0.003)	0.192	0.841
	(ln) bite force	1.184	0.003			

Normality test (Shapiro-Wilk) $p > 0.05$.
Constant variance test: $p > 0.05$.
ln, logarithmic transformation.

clinical oral examination; such adaptation was required to enable its use in a larger sample, and this may be considered as a potential limitation of this study. However, it is important to mention that the examiner was properly trained before examinations and this index includes a wide range of characteristics, and it has the advantage of not assign great weight to the aesthetic component as other indexes [8,9].

It is also important to consider that the properties of the food being chewed, in terms of its hardness, fat content, size, and structure may influence the evaluations [31], and the relatively softer consistency of the gum may facilitate chewing. Thus, the use of other types of food would be advisable when measuring masticatory performance and behavior due to the complexity of the chewing function.

Chewing difficulties lead to alterations in food preference, which ultimately may be related to unbalanced intake of foods and nutrition [38]. The present findings show the importance of considering sex differences when evaluating masticatory function among different populations and conditions, including feeding and/or swallowing disorders, both in scientific research and in clinical practice; in addition, normative data may help health professionals in understanding the complexity of the function, planning and assessing myofunctional treatments outcomes.

5. Conclusion

The findings of the present study support the existence of sex differences in many masticatory aspects of function and behavior, drawing attention to the importance of understanding the mechanisms involved in masticatory function. It may enable health professionals to act on the prevention of eating disorders, facial and dental impairments and on the assessment of sex-specific treatment outcomes in adolescents.

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