Factors related to masticatory performance in junior and senior high school students and young adults: A cross-sectional study

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Abstract

Purpose: Maintaining good masticatory function from a young age promotes lifelong health, yet limited studies have explored masticatory performance in young individuals. We investigated the relationship of sex, age, and individual oral functions with masticatory performance among junior and senior high school students and young adults.

Methods: This cross-sectional study included students aged 12–13, 14–15, and 16–17 years (groups S1, S2, and S3, respectively) and young adults aged 20–40 years (group YA). We assessed oral functions, the number of functional teeth, and anthropometric measurements. Masticatory performance was evaluated using color-changeable chewing gum. We analyzed sex-related differences in each group and age-related differences in each sex. Multiple linear regression analysis was performed using masticatory performance as the dependent variable to investigate related factors.

Results: Among the 522 children and 100 young adults, males exhibited significantly higher masticatory performance than females in groups S1, S3, and YA. Among males, groups S2, S3, and YA exhibited significantly higher masticatory performance than group S1. Among females, group S2 exhibited higher masticatory performance than groups S1 and S3. Male sex, the maximum occlusal force and tongue pressure, and the number of functional teeth were significantly correlated with masticatory performance.

Conclusions: Masticatory function development differed by sex, with males exhibiting higher masticatory performance than females. We identified that male sex, the maximum occlusal force and tongue pressure, and the number of functional teeth were significantly associated with masticatory performance. Our findings provide a basis for masticatory performance assessment in different age groups.

Keywords: Bite force, Chewing gum, Child, Mastication, Young adult

1. Introduction

Masticatory function is associated with various health-related factors. In previous studies with children, the masticatory performance of normal-weight children was higher than that of overweight/obese children in the 8–12-year-old group[1], and children with caries-free permanent first molars had higher masticatory performance than children with caries in the 12–14-year-old group[2]. In a study with participants of various age groups, from 12 to more than 60 years, participants with subjective masticatory discomfort had low quality of life scores[3]. Low masticatory performance was associated with decreased intake of certain nutrients in Japanese male workers[4], an increased risk of diabetes among 40–74-year-olds, and carotid intima-media thickness progression among 50–79-year-olds[5,6]. Moreover, low masticatory performance at baseline caused progression to frailty after 2 years among community-dwelling individuals aged 65 years or older[7]. A meta-analysis showed an association between subjective chewing problems and the risk of malnutrition[8]. These findings indicate that masticatory performance is important for lifelong health and should be managed from a young age so that it can be developed and maintained appropriately. Thus, dentists must understand the factors associated with masticatory performance.

Mastication is a comprehensive process comprising multiple factors, including individual oral functions such as the maximum occlusal force and tongue pressure and tongue-lip motor function. Exploring their interrelationship is important for understanding the impact of these factors on masticatory performance. However, few studies have focused on these factors in adolescents and young adults. Only one study has investigated the development of masticatory performance in 6–17-year-olds according to sex[9]. Furthermore, although multivariate analysis has been used to identify factors
related to masticatory performance in older participants[10–13], to
the best of our knowledge, it has only been employed in one study
to investigate these factors in adolescents[14]. Therefore, further re-
search is required to examine these factors in greater detail in young
individuals.

Accordingly, we investigated the relationship between mas-
ticatory performance, individual oral functions, and other relevant
factors in junior and senior high school students and young adults
to identify the factors related to masticatory performance in these
populations.

2. Materials and Methods

2.1. Study design and participants

This was a post hoc analysis of our previous study[15]. This cross-
sectional study included students aged 12–13 (first grade of junior
high school; group S1), 14–15 (third grade of junior high school; group
S2), and 16–17 years (second grade of senior high school; group S3)
from two private junior and senior high schools situated in a city area
and young adults aged 20–40 years (group YA) who were recruited
from students or staff at a local university. None of the participants
had missing permanent teeth that were not remedied with fixed
dental prostheses, except for the third molars, congenitally missing
teeth, or teeth extracted for orthodontic treatment. The exclusion
criteria were as follows: severe dental caries, periodontal disease,
temporomandibular joint disorders, and current orthodontic treat-
ment.

The study was approved by the institutional ethics committee
and conducted in accordance with the tenets of the Declaration
of Helsinki. Parents or guardians of the children and young adults
provided written informed consent before participation.

2.2. Measured parameters

The measurement data from our previous study[15] were used
for analysis. The measurements were performed as described below.
Data for each participant were obtained within 1 day.

2.2.1. Masticatory performance

Masticatory performance was evaluated using color-change-
able chewing gum (Mastication Check Gum; Lotte Co., Ltd., Tokyo,
Japan)[16]. The gum color is green before chewing and changes
to red with mastication. Thus, masticatory performance could be
evaluated on the basis of gum color after chewing. The participants
were instructed to chew the gum for 60 strokes at a rate of one stroke
per second without limiting chewing to one side. After chewing,
the gum was covered with two polyethylene films and flattened to
a thickness of 1.5 mm using two glass plates. The color values, L*,
a*, and b*, were measured immediately using a colorimeter (CR13;
Konica Minolta Sensing, Tokyo, Japan) positioned at five points, that
is, the gum center and approximately 3 mm above and below and to
the left and right of the center. Based on these measurements, the
average values of L*, a*, and b* were calculated for each gum sample.

The masticatory performance index using color-changeable chew-
ing gum (MPIG) was calculated from the average values using the
following equation[16,17]:

\[
\Delta E = \sqrt{(L^*-72.3)^2 + (a^*-(−14.9))^2 + (b^*-33.0)^2}
\]

\[
\text{MPIG} = \frac{1}{9.55 \times 10^{-3}} \ln \left( \frac{-2.85 \times 10^7 \times \Delta E - 73.2}{1.35 \times 10^3} \right)
\]

where L*, a*, and b* are the coordinates in the CIELAB color space.
The L*, a*, and b* values before chewing were 72.3, −14.9, and 33.0,
respectively. A higher MPIG score indicates higher masticatory per-
formance.

2.2.2. Maximum occlusal force

The maximum occlusal force was measured using a portable oc-
cclusal force meter (GM10; Nagano Keiki Co., Ltd., Tokyo, Japan)[18,19].
Participants were seated in a relaxed posture and asked to bite the
biting part with their first molars on each side, first softly and then as
hard as possible for 3 s. We measured the maximum occlusal force
from each side, and the larger force was selected for evaluation.

2.2.3. Maximum tongue pressure

The maximum tongue pressure was measured using a tongue
pressure indicator (TPM-01; GC Corporate Center, Tokyo, Japan)
[20,21]. Participants were seated in a relaxed posture. Once the bal-
loon was placed in their mouths, they were instructed to press their
tongues to the palate with maximal force. Measurements were per-
formed thrice, and the highest value was considered for evaluation.

2.2.4. Tongue-lip motor function

Tongue-lip motor function was evaluated using a measuring
instrument (TKK-3351; Takei Scientific Instruments Co., Ltd., Niigata,
Japan)[12]. Participants were instructed to repeatedly pronounce the
syllables “pa,” “ta,” and “ka” as rapidly as possible in 5 s. The average
number of repetitions was selected as the tongue-lip motor function
value.

2.2.5. Number of functional teeth

Functional teeth were defined as healthy and treated, including
pontics, in fixed prostheses. For groups S1, S2, and S3, we obtained
data from annual dental examinations conducted at the respective
schools. For the YA group, one of the researchers and dentists per-
formed dental assessments.

2.2.6. Anthropometric measurements

For groups S1, S2, and S3, height and weight data were obtained
from the annual examination results at each school. Participants
from the YA group provided their height and weight data in a de-
identified manner.

2.3. Statistical analysis

The Shapiro–Wilk test was used to evaluate the normality of data
distribution. To investigate sex-related differences in the MPIG score
in each age group, Student’s t-test was applied after Levene’s test
for homogeneity of variances. Age-related differences in the MPIG
score for each sex were evaluated using Tukey’s honest significant
difference test. Spearman’s rank correlation coefficients ($r_s$) were calculated to investigate the univariate correlations between the MPIG score and measured variables. Finally, multiple linear regression analysis was performed with the MPIG score as the dependent variable and age, sex, oral functions, the number of functional teeth, and anthropometric measurements as independent variables, with consideration for multicollinearity. The statistical significance level was set at $p = 0.05$. Data were analyzed using the JMP software (version 8.0; SAS Institute, Cary, NC, USA).

### 3. Results

#### 3.1. Participant characteristics

In this study, measurements were performed on 522 junior and senior high schools students and 100 young adults. Table 1 shows the characteristics of the study participants according to the Shapiro–Wilk test results.

#### 3.2. Sex

Male participants demonstrated significantly higher MPIG scores than did their female counterparts in the S1, S3, and YA groups.

#### 3.3. Age

Among males, the S2, S3, and YA groups had significantly higher MPIG scores than did the S1 group. Among females, the S2 group had higher MPIG scores than did the S1 and S3 groups.

#### 3.4. Individual oral functions, the number of functional teeth, and anthropometric measurements

Spearman’s rank correlation coefficients are shown in Table 2. All measured variables were significantly correlated with the MPIG score but exhibited slight or fair correlations. Among these, the maximum $r_s$ was 0.31 for the maximum occlusal force, followed by 0.28 for the maximum tongue pressure.

### 3.5. Factors related to masticatory performance

The adjusted coefficient of determination in the multiple linear regression analysis was 0.21 ($p < 0.01$), and sex, the maximum occlusal force and tongue pressure, and the number of functional teeth were identified as factors significantly related to the MPIG score (Table 3). Low variance inflation factors indicate that the model structure and selection of independent variables are appropriate.

### 4. Discussion

In the present study, sex, the maximum occlusal force and tongue pressure, and the number of functional teeth were identified as factors significantly related to masticatory performance in junior and senior high school students and young adults. Notably, this study included the largest number of participants among studies evaluating masticatory performance in young individuals. Therefore, our results can be used to establish standards for masticatory performance assessment based on the color-changeable chewing gum method for these age groups.

### Table 1. Characteristics of participants

|                          | S1              | S2              | S3              | YA               |
|--------------------------|-----------------|-----------------|-----------------|-----------------|
| N                        | Male: 118       | Male: 99        | Male: 71        | Male: 88        |
| Age (range) (yr)          | 12 (12–13)      | 12 (12–13)      | 14 (14–15)      | 16 (16–17)      |
| Masticatory performance:  |                 |                 |                 |                 |
| MPIG (score)              | [75.9–81.8]*    | [69.9–76.4]     | [81.0–89.2] $\dagger$ | [77.9–84.4] $\dagger$ |
| Maximum occlusal force (N)| 338.0 [223.8, 428.0] | 364.0 [250.0, 468.0] | 427.0 [292.0, 528.0] | 372.5 [271.0, 501.3] |
| Maximum tongue pressure (kPa)| 40.5 [33.7, 47.1] | 40.1 [33.3, 46.2] | 43.3 [34.4, 48.5] | 40.8 [35.6, 46.7] |
| The number of functional teeth | 25 [24, 27] | 26 [24, 28] | 28 [27, 28] | 28 [26, 28] |
| Height (cm)               | 153.5 [150.0, 157.6] | 153.4 [149.7, 157.0] | 166.0 [161.4, 170.6] | 158.1 [154.1, 160.8] |
| Weight (kg)               | 42.3 [39.5, 49.9] | 43.0 [38.1, 49.0] | 52.5 [48.3, 58.0] | 49.8 [45.5, 53.3] |

*: $p < 0.05$, **: $p<0.01$ vs. female counterpart (Student’s t-test). $\dagger$, $\ddagger$: $p < 0.05$ vs. S1, $p < 0.01$ vs. S1, and $p < 0.05$ vs. S2, respectively, in each sex (Tukey's honestly significant difference test).

### Table 2. Correlation between masticatory performance and measured variables

|                          | $r_s$ | $p$ value |
|--------------------------|-------|-----------|
| Maximum occlusal force   | 0.31  | <0.01     |
| Maximum tongue pressure  | 0.28  | <0.01     |
| Tongue-lip motor function: oral diadochokinesis rate | 0.14  | <0.01     |
| The number of functional teeth | 0.21  | <0.01     |
| Height                   | 0.24  | <0.01     |
| Weight                   | 0.27  | <0.01     |

$r_s$: Spearman’s rank correlation coefficient. Statistically significant $p$ values are indicated in bold type.

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In our previous study, we analyzed sex and age differences in individual oral functions (the maximum occlusal force and tongue pressure and tongue-lip motor function) in the same study population[15]. As individual oral functions represent only some of the factors affecting masticatory performance, we conducted this study to analyze the relationship of individual oral functions and other relevant factors with masticatory performance in this population.

The color-changeable chewing gum method selected in this study was based on a method introduced in a previous consensus paper on the evaluation of masticatory performance[22]. The gum color is yellowish-green before chewing and changes to red with chewing; thus, we can evaluate the masticatory performance on the basis of gum color after chewing[16]. The color changes can be measured using special devices, such as a colorimeter, but can also be evaluated visually[23,24]; hence, anyone can easily evaluate masticatory performance using the gum. This method has been employed in large-scale medical surveys[25,26]. Since this method can be applied to participants of various ages and dentition statuses, including preschool children[17], adolescents[14], older adults[27], complete denture wearers[28], and maxillofacial prosthesis wearers[29], it is useful for the assessment and management of masticatory performance over a full lifespan. As few studies have evaluated masticatory performance in junior and senior high school students using the color-changeable chewing gum method[14,30], the assessment standard in this population is unknown. Thus, the results of this study are meaningful in that they can be used to establish standards for masticatory performance assessment based on this method in adolescents and young adults. However, we should recognize that these standards were derived from the data of a few participants with a low number of functional teeth due to unerupted teeth, congenitally missing teeth, and teeth extracted for orthodontic treatment.

In the present study, males exhibited higher masticatory performance than females in the S1, S3, and YA groups, which is consistent with the findings of most previous studies[31–33], with the exception of one study, in which 12- and 16-year-old females had higher masticatory efficiency than did males[9]. The same trend was also observed in our previous study[15] and other studies regarding the maximum occlusal force[19] and maximum tongue pressure[21]. The MPIG score is obtained from the number of strokes converted from ΔE, which denotes the color changes before and after chewing; thus, it can be treated as a ratio scale statistically[17]. In our study, the average MPIG score was higher in males than in females by 7.8% in group S1, 5.5% in group S2, 15.1% in group S3, and 17.1% in group YA.

The growth process, including the development of oral functions, differs according to sex[18,19,21]. Therefore, we analyzed the developmental aspects of mastication for each sex separately. In males, we observed a tendency toward an increase in the average MPIG score with age. Moreover, male participants in the S2, S3, and YA groups had significantly higher masticatory performance than those in group S1, which is in line with previously reported findings[9,34]. Development from S1 to S2 is closely associated with the period of body growth in males[35]. We did not find statistically significant differences between the S2, S3, and YA groups. More measurements are needed to clarify whether masticatory performance develops from S2 to YA.

In females, we observed a peak in masticatory performance in group S2, that is, female participants in group S2 had significantly higher masticatory performance than did those in the S1 and S3 groups. Previous studies have reported the same tendency, with peaks in masticatory performance[9] and the maximum occlusal force[18] at approximately 15 years of age. In this study, multiple linear regression analysis indicated that the maximum occlusal force and tongue pressure were related to masticatory performance. The median values of these variables in the female S2 group were higher than those in the S1 and S3 groups, which is one of the reasons for the peak masticatory performance observed in the female S2 group. Moreover, the maximum occlusal force and tongue pressure are related to skeletal muscle mass[36,37]. To our knowledge, no study has investigated muscle mass growth in adolescents. However, our government agency reported that the peak of estimated energy requirement, calculated through the basal metabolic rate, was observed in 12- to 14-year-old Japanese females[38]. Previous studies have indicated an association between basal metabolism and muscle metabolism or fat-free mass[39,40]; it is possible that younger Japanese females aged 12–14 years have more muscle mass than older Japanese females. Thus, we believe this phenomenon may be the reason behind the observation that the maximum occlusal force and tongue pressure were higher in females in group S2 than in those in group S3 in the present study.

In this study, all evaluated parameters—individual oral functions (the maximum occlusal force and tongue pressure and tongue-lip motor function), the number of functional teeth, and anthropometric measurements (height and weight)—were significantly associated with masticatory performance. However, the correlation coefficients were not high; the maximum r was 0.31 for the maximum occlusal force and 0.28 for the maximum tongue pressure. A previous study indicated that masticatory performance evaluated using the color-changeable chewing gum method in preschool children was significantly associated with the number of healthy teeth but not with the maximum occlusal force, height, and weight[17]. This discrepancy in the findings is thought to be due to the differences in factors related

| Independent variables                  | β     | p value | VIF |
|----------------------------------------|-------|---------|-----|
| Age                                    | 0.09  | 0.05    | 1.49|
| Sex (Male)                             | 0.25  | <0.01   | 1.19|
| Maximum occlusal force                 | 0.11  | 0.02    | 1.39|
| Maximum tongue pressure                | 0.17  | <0.01   | 1.30|
| Tongue-lip motor function: oral diadochokinesis rate | 0.07  | 0.08    | 1.14|
| The number of functional teeth         | 0.11  | <0.01   | 1.23|
| Weight                                 | 0.04  | 0.37    | 1.55|

β, standardized partial regression coefficient; VIF, variance inflation factor. Statistically significant p values are indicated in bold type.
to masticatory performance among preschool children, high school students, and young adults.

Considering the multicollinearity of weight and height, we selected weight for conducting multiple linear regression because of its high correlation coefficient with masticatory performance. We identified sex, the maximum occlusal force and tongue pressure, and the number of functional teeth as significant factors. To masticate chewing gum efficiently, repeated cycles are needed in which the gum is placed on the teeth using the tongue and then compressed by the teeth. Therefore, it is reasonable to assume that the number of functional teeth and maximum occlusal force and tongue pressure are significant factors.

Few studies have employed multivariate analysis to investigate the factors associated with masticatory performance, including individual oral functions. The maximum occlusal force was found to be a significant factor in male adolescents[14], whereas the maximum occlusal force and number of residual teeth were significant factors in older adults[10–13]. These findings are similar to those obtained in the present study.

This study has some limitations. First, the adjusted coefficient of determination in the multiple linear regression analysis was 0.21, indicating the existence of other factors related to masticatory performance. Masticatory performance has been associated with malocclusion[41,42], mandibular movement[43,44], and the occlusal contact area[45]. Furthermore, after adjusting for the maximum occlusal force and tongue pressure, which tended to be higher in males than in females[19,21,33], sex was identified as a significant factor, indicating that masticatory performance is related to other sex-specific factors, such as eating behavior which differs according to sex[46]. Further studies should include these factors in the analysis to reveal more details. Second, our study might have had a sampling bias, as all participants had healthy natural dentitions. Moreover, our results may not be applicable to patients with poor oral health. Finally, this was a cross-sectional study; thus, a longitudinal study is required to analyze changes in oral functions over time among the same participants.

5. Conclusions

In conclusion, we have demonstrated the average values and distributions of masticatory performance evaluated using the color-changeable chewing gum method in junior and senior high school students and young adults. Masticatory performance was higher in males than in females among students aged 12–13 and 16–17 years, as well as in young adults. Among males, students aged 14–15 and 16–17 years and young adults had higher masticatory performance than did those aged 12–13 years. Among females, students aged 14–15 years had higher masticatory performance than did those aged 12–13 and 16–17 years. Male sex, the maximum occlusal force and tongue pressure, and the number of functional teeth were identified as factors associated with masticatory performance among these age groups. Our study results will contribute to the evaluation and management of masticatory performance among junior and senior high school students and young adults.

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Authors’ contributions

YH designed the study, curated the data, and drafted the manuscript. AH and CK were responsible for data collection. RG designed the study. RG, HS, KY, and MO curated the data and assembled the references. SM was a project administrator who reviewed and edited the manuscript. All authors have read and approved the final version of the manuscript.

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Conflict of interest statement

The authors declare that they have no conflicts of interest.

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Conflict of interest statement

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