Journal of Dentistry 174 (2026) 106867

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Association between masticatory performance and physical fitness in Japanese elementary schoolchildren: The Osaka MELON Study

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ARTICLE INFO

Keywords:
Masticatory performance
Physical fitness
School children
Sex differences

ABSTRACT

Objectives: This study aimed to examine the association between masticatory performance and physical fitness in Japanese elementary school children.
Methods: This cross-sectional study included 1,225 children (608 boys and 617 girls) aged 9-10 years in Osaka, Japan. Masticatory performance was assessed using a color-changeable chewing gum. Physical fitness was evaluated using seven standardized tests (handgrip strength, sit-ups, side-to-side jump, 20-m shuttle run, 50-m sprint, standing long jump, and softball throw), and a composite physical fitness score was calculated as the mean of sex-standardized z-scores. Associations between masticatory performance and physical fitness were examined using Pearson's correlation coefficients and multivariable linear regression analyses adjusted for height and weight. Sex-stratified analyses were also performed.
Results: In the overall analysis, masticatory performance was significantly associated with side-to-side jump, 20-m shuttle run, 50-m sprint, softball throw, and the composite physical fitness score. In boys, significant correlations were observed for sit-ups, 20-m shuttle run, softball throw, and the composite physical fitness score, whereas in girls, only the 20-m shuttle run showed a significant correlation. In sex-stratified multivariable analyses, masticatory performance was significantly associated with the composite physical fitness score in boys, but not in girls.
Conclusion: Masticatory performance was associated with several physical fitness components, as well as the composite physical fitness score, in Japanese elementary school children, particularly in boys.
Clinical significance: These findings highlight the importance of developing and maintaining adequate masticatory function during childhood, which was associated with higher physical fitness in the present study.

1. Introduction

Physical fitness during childhood plays a crucial role in current health status and future health outcomes. Lower levels of physical fitness in school-aged children have been associated with adverse health outcomes, including obesity, cardiovascular risk factors, and reduced physical activity later in life [1–5]. Accordingly, identifying factors related to physical fitness during school age is an important public health issue.

Masticatory function is an essential component of oral function and plays a central role in food intake and digestion. It contributes to food breakdown and may affect nutrient intake, which is important for

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https://doi.org/10.1016/j.jdent.2026.106867
Received 21 April 2026; Received in revised form 10 June 2026; Accepted 26 June 2026
Available online 28 June 2026

growth and development during childhood [6]. Impairments in masticatory function have been linked to poor dietary quality and poor nutritional profiles [7,8]. Beyond its role in oral health, masticatory function has attracted increasing attention for its potential associations with systemic health outcomes. Previous studies in adults and older populations have reported associations between masticatory function and physical function [9,10], frailty [11,12], and quality of life [13,14]. These findings suggest that masticatory function may reflect broader aspects of functional health, rather than being limited to the oral cavity.

In contrast, evidence regarding the relationship between masticatory function and physical fitness in children remains limited. Though several studies have examined oral health indicators, such as dental caries or occlusal status, in relation to growth or obesity [15–17], few studies have directly assessed the association between objectively measured masticatory function, which is defined as masticatory performance, and physical fitness in school-aged children. Moreover, physical fitness is a multidimensional construct comprising various components, such as muscular strength, power, agility, and cardiorespiratory endurance. Many previous studies have focused on individual fitness measures [18,19], which may not adequately capture overall physical fitness. The use of composite fitness scores may provide a more comprehensive assessment of physical fitness and facilitate the examination of its associations with other functional outcomes [20].

In addition, sex differences in physical fitness and biological maturation are evident during school age [21], and such differences may affect the relationship between masticatory performance and physical fitness. However, sex-specific associations in this context have not been sufficiently explored.

The aim of this study was to examine the association between masticatory performance and physical fitness in Japanese elementary school children using a composite physical fitness score. Whether this association differed between boys and girls was further explored.

2. Materials and methods

2.1. Study participants

The study participants were 1225 fourth-grade elementary schoolchildren (9- to 10-year-olds, 608 boys and 617 girls) attending 29 public elementary schools in Osaka City that agreed to participate in the Osaka MELON (Mastication research in Elementary school student teaching applying LONgitudinal) Study [22]. Physical examinations and dental checkups were conducted at the participating schools between April 2023 and March 2024. This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [23].

2.2. Ethics approval and consent to participate

The study was approved by the Institutional Review Board of the University (approval number R5-E34-1) and conducted in accordance with the revised Declaration of Helsinki. Informed consent was obtained from the participants through an opt-out approach, allowing them to refuse participation if they did not wish to be involved in the study.

2.3. Dental examinations

In the dental examinations, the number of erupted teeth was recorded, and the Decayed, Missing, and Filled Teeth (DMFT) index was used to evaluate caries in permanent teeth, whereas the decayed, missing, and filled teeth (dmft) index was used for primary teeth, by visual inspection with a dental mirror under lighting according to criteria established by the World Health Organization [24]. Dentition status was recorded, and the Hellman dental development stage (IIA, IIC, IIIA, IIIB, and IIIC) was evaluated. In addition, the presence of malocclusion, the condition of dental plaque, and the presence of gingival inflammation were evaluated visually. All dental examinations were conducted by school dentists at each elementary school.

2.4. Masticatory performance examination

Masticatory performance was evaluated using a color-changeable chewing gum (Xylitol Mastication Check Gum, Lotte Co., Ltd., Tokyo, Japan) and its web application [25]. Participants were asked to chew a test gum for one minute, with the chewing rate controlled at once per second by an electronic metronome. After chewing 60 times, each prepared sample was placed on a dedicated sheet for color correction of images captured by a tablet camera under fluorescent light conditions. The color change of the gum was evaluated by the web application and scored from 1.0 to 10.0.

2.5. Assessment of physical fitness

Physical fitness was assessed using the following seven components: handgrip strength, sit-ups, side-to-side jump test, 20-m shuttle run test, 50-m sprint, standing long jump, and softball throw. All tests were conducted according to the standardized protocol of the Japanese physical fitness test for school-aged children [26].

A composite physical fitness score was calculated to represent overall physical fitness in a single measure. Each physical fitness component, handgrip strength, sit-ups, side-to-side jump test, 20-m shuttle run test, 50-m sprint, standing long jump, and softball throw, was first standardized for each sex by calculating z-scores. The physical fitness score was then calculated as the mean of the z-scores of the seven components [20]. Higher scores indicate better overall physical fitness. For the 50-m sprint, z-scores were multiplied by -1 so that higher values consistently indicated better physical fitness across all components.

2.6. Statistical analysis

Differences between boys and girls were examined using Student's *t*-test for continuous variables and the chi-squared test for categorical variables. Pearson's correlation coefficients were calculated to examine the associations between masticatory performance and individual physical fitness components. Multivariable linear regression analyses were conducted to examine the association between masticatory performance and the physical fitness score. Two models were conducted: Model 1 was adjusted for sex, and Model 2 was further adjusted for height and weight. Sex-stratified analyses were also performed, and all analyses were repeated separately for boys and girls using the same analytical approach.

All analyses were conducted using IBM SPSS Statistics 28 (SPSS Japan Inc., Tokyo, Japan), and the significance level was set at 5%.

3. Results

3.1. Participants' characteristics

A total of 1225 children (608 boys and 617 girls) were included in the analysis. The characteristics of the participants are shown in Table 1. Boys showed significantly higher values for weight, body mass index, dmft index, side-to-side jump test, 20-m shuttle run test, softball throw, and masticatory performance, and faster 50-m sprint times, whereas girls showed a higher DMFT index. The distribution of Hellman dental development stages also differed significantly between boys and girls, with a higher proportion of girls in stages IIIB and IIIC.

3.2. Correlations between masticatory performance and physical fitness components

Table 2 shows the correlations between masticatory performance and individual physical fitness components. In all study participants,

Table 1
Characteristics of study participants.

Survey item	All	Boys	Girls	p-value
n	1225	608	617	
Height, cm	134.2 ±6.2	134.0 ±5.9	134.4 ±6.5	0.291
Weight, kg	31.2±7.2	31.6±7.8	30.8±6.6	0.047
BMI	17.2±2.9	17.4±3.1	16.9±2.6	0.002
dmft index	1.3±1.9	1.4±2.1	1.2±1.8	0.043
DMFT index	0.2±0.6	0.2±0.6	0.3±0.7	0.015
Hellman dental development stage				
IIC	99 (8.1)	58 (9.5)	41 (6.6)	<0.001
IIIA	285 (23.3)	190 (31.3)	95 (15.4)	
IIIB	803 (65.6)	348 (57.2)	455 (73.7)	
IIIC	38 (3.1)	12 (2.0)	26 (4.2)	
Handgrip strength, kg	14.1±3.5	14.1±3.6	14.1±3.5	0.928
Sit-ups, times	16.9±5.7	17.2±5.9	16.6±5.5	0.055
Side-to-side jump test, times	33.3±8.0	34.1±8.4	32.5±7.4	<0.001
20-m shuttle run test, times	34.5 ±16.9	38.9 ±18.4	30.1 ±14.1	<0.001
50-m sprint, seconds	10.1±1.0	9.9±1.0	10.2±0.9	<0.001
Standing long jump, cm	137.1 ±41.8	139.5 ±20.1	134.9 ±55.3	0.054
Softball throw, m	14.0±6.5	16.9±7.3	11.2±4.1	<0.001
Masticatory performance	7.6±1.7	7.8±1.6	7.4±1.7	<0.001

Mean ± SD or n (%)
BMI: body mass index; DMFT: decayed, missing and filled teeth
Student's t test or chi-squared test compared by sex

Table 2
Correlations between masticatory performance and physical fitness.

	All (n=1225)		Boys (n=608)		Girls (n=617)	
	r	p-value	r	p-value	r	p-value
Handgrip strength	-0.020	0.486	-0.024	0.561	-0.016	0.690
Sit-ups	0.053	0.066	0.106	0.009	-0.013	0.747
Side-to-side jump test	0.075	0.009	0.074	0.068	0.055	0.175
20-m shuttle run test	0.139	<0.001	0.128	0.002	0.101	0.012
50-m sprint	-0.080	0.005	-0.062	0.126	-0.060	0.134
Standing long jump	0.020	0.491	0.078	0.054	-0.007	0.869
Softball throw	0.118	<0.001	0.130	0.001	-0.003	0.945
Physical fitness score	0.083	0.003	0.121	0.003	0.045	0.262

r: Pearson correlation coefficient

masticatory performance was significantly correlated with the side-to-side jump test, 20-m shuttle run test, 50-m sprint (lower times indicate better performance), softball throw, and physical fitness score. In boys, masticatory performance was significantly correlated with sit-ups, 20-m shuttle run test, softball throw, and physical fitness score. In girls, masticatory performance was significantly correlated with the 20-m shuttle run test.

3.3. Association between masticatory performance and the physical fitness score

The results of the multivariable linear regression analyses are presented in Table 3. In the overall analysis, masticatory performance was significantly associated with the physical fitness score in Model 1 and Model 2. In sex-stratified analyses, masticatory performance was significantly associated with the physical fitness score in boys across all statistical models. In girls, no significant association was observed in any statistical model. To formally assess whether the association differed by sex, an interaction term between sex and masticatory performance was included in the regression model. The interaction was not significant (P=0.220).

Table 3
Multiple regression analysis of the association between masticatory performance and the physical fitness score.

	n		B	95%CI	p-value
All	1225	Model 1	0.031	0.010 - 0.051	0.003
		Model 2	0.031	0.012 - 0.051	0.002
Boys	608	Model 1	0.049	0.017 - 0.081	0.003
		Model 2	0.044	0.014 - 0.074	0.005
Girls	617	Model 1	0.015	-0.011 - 0.041	0.262
		Model 2	0.020	-0.005 - 0.045	0.124

Dependent variable: Physical fitness score
Independent variable: Masticatory performance
B: Unstandardized regression coefficient for masticatory performance: CI: Confidence interval
Model 1: Adjusted for sex (all participants) or crude model (sex-stratified analyses)
Model 2: Model 1 + adjusted height and weight

4. Discussion

In this cross-sectional study of Japanese elementary school children, the association between masticatory performance and physical fitness was examined using a composite fitness score derived from multiple fitness tests. Masticatory performance was positively associated with the physical fitness score in the overall analysis after adjustment for sex, height, and weight. In sex-stratified analyses, a significant association between masticatory performance and the physical fitness score was observed in boys, whereas no significant association was found in girls.

A few previous studies in children have reported associations between masticatory performance and physical fitness. For example, studies involving sixth-grade elementary school children [27] and first-year junior high school students [28] showed that children with higher masticatory performance tend to exhibit better physical fitness. These findings are consistent with the results of the present study. However, previous studies focused primarily on individual fitness components and did not assess overall physical fitness using a composite measure. In addition, limitations such as relatively small sample sizes and the lack of sex-stratified or multivariable analyses may have impeded a more comprehensive evaluation of these associations. The present study extends previous research by incorporating a larger sample, examining sex-specific associations, and applying multivariable analyses that account for basic anthropometric factors, thereby providing a more comprehensive assessment of the relationship between masticatory performance and physical fitness.

The present findings suggest that better masticatory performance is associated with higher overall physical fitness in school-aged children, particularly in boys. This association remained evident after adjustment for basic anthropometric factors, indicating that the relationship cannot be explained solely by differences in body size. In this study, the use of a composite physical fitness score facilitated the capture of overall physical fitness across multiple domains, including muscular strength, power, agility, and endurance. This approach has been used in previous studies to summarize children's physical fitness by a single indicator and to reduce the complexity associated with multiple correlated fitness measures [20,29,30]. Although this composite score does not represent a standardized or validated scale, it provides a reasonable summary measure of overall physical fitness and facilitates the examination of associations with other functional outcomes. The consistent increase in all fitness components across quartiles of the physical fitness score supports its interpretability as an indicator of overall physical fitness in this population (Supplementary Table). The observed association between masticatory performance and this composite measure suggests that masticatory performance may reflect broader aspects of functional development, rather than being related to a single fitness component. However, although the observed association was statistically significant, its magnitude was relatively modest. Therefore, the practical

significance of this finding remains unclear. Further studies are needed to determine whether differences in masticatory performance translate into meaningful differences in physical fitness and related health outcomes.

Several mechanisms may partly explain the observed association between masticatory performance and physical fitness. One plausible explanation is that better masticatory performance facilitates more effective food breakdown, which may contribute to adequate nutrient intake [7,8]. Adequate nutrient intake during childhood supports muscle function and metabolic processes, which may in turn affect physical fitness [31]. In addition, masticatory behavior itself may reflect neuromuscular function. Mastication involves coordinated activity of the masticatory muscles and central nervous system [32], and higher masticatory performance may reflect better neuromuscular control and muscle function [33]. Such functional capacity may be linked to broader aspects of physical fitness, particularly components related to endurance and power, as observed in the present study.

In the present study, a significant association between masticatory performance and physical fitness was observed in boys, but not in girls. In boys, masticatory performance was correlated with multiple physical fitness components, and its association with the composite physical fitness score remained significant after adjustment for anthropometric factors. However, the interaction between sex and masticatory performance was not significant ($P = 0.220$). Therefore, the present findings do not provide clear evidence that the association differs by sex, and the sex-stratified findings should be interpreted with caution. One possible explanation for the observed pattern of results is that physical fitness in girls at this age may be affected by factors not assessed in the present study, such as biological maturation, lifestyle habits, or psychosocial factors [34,35]. In addition, sex-specific differences in biological maturation and developmental timing may partly affect the relationship between masticatory performance and physical fitness [36]. Importantly, the absence of a significant association in girls does not indicate that masticatory performance is unrelated to physical fitness in this group.

The present findings highlight the potential importance of effective masticatory function during school age, a critical period for physical development. Masticatory function is often considered primarily in the context of oral health. The observed association with physical fitness in the present study suggests that masticatory performance may also be linked to broader aspects of functional development. From a public health perspective, these results support the importance of promoting adequate chewing habits and developing oral function during childhood. The observed association between masticatory performance and physical fitness suggests that oral function may be relevant to physical development during this period. Given the observational nature of the present study, these implications should be interpreted cautiously. However, the findings suggest that adequate chewing habits and effective masticatory function during school age may be an important component of healthy overall development.

There are several limitations in this study. First, due to the cross-sectional study design, causal relationships between masticatory performance and physical fitness cannot be established. Longitudinal studies are therefore needed to clarify the temporal sequence and potential causal pathways underlying this association. Second, information on potentially important factors such as dietary intake, habitual physical activity, and socioeconomic status was not available and may have affected the observed associations. Although these factors could partly explain the relationship between masticatory performance and physical fitness, the present study was conducted in a school-based setting and aimed to examine their association under routine conditions. Future studies incorporating these factors are warranted. Third, most participants were in the mixed dentition stage. Physiological tooth exfoliation, eruption, and temporary tooth mobility during this developmental period may have influenced the assessment of masticatory performance. Consequently, the measured masticatory performance may have been affected not only by functional capacity but also by developmental changes in dentition.

5. Conclusions

Masticatory performance was significantly associated with several physical fitness components, as well as with the composite physical fitness score, in Japanese elementary school children, particularly in boys. These findings suggest that adequate masticatory function during childhood is associated with physical fitness and may be relevant to healthy functional development.

Funding information

This study was supported by the Lotte Research Promotion Grant (No. 2025C0002).

Data availability statement

The data used in this study are not publicly available due to confidentiality. For further information, the authors should be contacted.

CRediT authorship contribution statement

Risa Hiramatsu: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Takayuki Kosaka:** Methodology, Investigation, Formal analysis, Conceptualization. **Masatoshi Otsugu:** Methodology, Investigation, Conceptualization. **Tatsuya Nishimoto:** Methodology, Investigation. **Masayuki Yoshimatsu:** Methodology, Investigation. **Yuki Murotani:** Investigation. **Norimasa Sakanoshita:** Methodology, Investigation, Conceptualization. **Yasuhiko Ueda:** Methodology, Investigation. **Kazuhiko Nakano:** Supervision, Conceptualization. **Kazunori Ikebe:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

Acknowledgements

The authors would like to thank Yuko Togi and other members of the Osaka City Board of Education, the members of the Osaka City Associations of School Dentists, and the teachers and students at elementary schools in Osaka City for their extensive cooperation in the survey.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jdent.2026.106867.

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