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ORIGINAL RESEARCH

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Relationship between eating behaviors and muscle strength among Chinese male adolescents

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Abstract

The impact of eating behaviors on physical fitness and overall health is widely recognized. However, the specific effect of late-night eating on physical fitness and the relationship between unhealthy eating habits and muscle strength in adolescents have not been explored yet. This study was designed to investigate the relationship between eating behaviors and muscle strength among Chinese male adolescents. The eating habits of 1916 high school students (mean age = 16.7 $\pm$ 0.8) were assessed by a questionnaire comprising items related to the consumption of breakfast and frequency of late-night food intake. Muscle strength was measured by grip strength (upper body strength) and standing long jump (lower body strength) tests. To discern the relationship between eating behaviors and muscle strength, a covariance analysis (ANCOV) was performed by making adjustments for potential confounding variables. The final adjusted model suggested a significant relationship between grip strength and the frequency of breakfast consumption (a higher frequency was related with better grip strength; $p < 0.001$) and late-night eating (a lower frequency was linked with better grip strength; $p = 0.002$). Few unhealthy eating behaviors were associated with better grip strength and standing long jump performance ($p < 0.001$ and $p = 0.026$, respectively). These findings suggest that consumption of breakfast, reduction of the late-night eating, and decreased unhealthy eating habits may improve muscle strength and function in male adolescents.

Keywords

Breakfast; Late-night eating; Grip strength; Adolescents; Cross-sectional study

1. Introduction

Muscle strength is essential for physical health as it plays a central role in daily life for mobility, balance and overall physical function [1, 2]. Fully functional muscles prevent from falls, injuries and other adverse health outcomes. Adequate muscle strength is linked with improved cardiometabolic health and a lower risk of type 2 diabetes [3], cardiovascular disease (CVD) [4] and metabolic syndrome [5]. Muscle strength helps maintain independence and quality of life [6]. Hence, it is important to understand the factors that influence muscle strength to promote healthy development of adolescents and prevent chronic diseases.

To protect muscle strength, it is necessary to engage in daily physical activity and exercise. However, it may be challenging to find sufficient time for exercise, particularly for Chinese adolescent students who are preparing for Gaokao (university entrance examination). These students usually study more than 12 h (8 AM to 8 PM) daily. Daily eating behaviors may affect overall health of a person. A study conducted in Japan indicated that engaging in more than two unhealthy eating behaviors was significantly associated with increased depressive symptoms [7]. Another study revealed that unhealthy eating behaviors were independently associated with an increased risk of CVD [8]. Similarly, another study demonstrated that irregular breakfast consumption and late-night eating may cause nutritional imbalance [9], decreasing muscle strength. Poor nutrient intake is one of the risk factors for decreased muscle strength [10]. Contrarily, regular breakfast consumption and increased physical activity are associated with improved muscle function preventing loss of muscle strength [11]. These findings suggest that eating behaviors significantly impact muscle function and overall physical health. Although the impact of eating behaviors on muscle function are unclear, a correlation among unhealthy dietary habits, lower limb muscle endurance, and poor aerobic fitness in children of the age groups 6–10 attending primary school has been observed [12]. Similarly, studies conducted in Japan and China showed a positive association between the frequency of breakfast consumption, muscle strength, and overall physical fitness in adults [13, 14]. However, a few studies have examined the relationship among late-night eating, frequency of breakfast consumption, unhealthy eating habits and muscle strength in adolescents. Adolescence is a critical transitional period of age that shapes long-term health trajectory of an individual. Therefore, the development of healthy eating behaviors during

adolescence are essential. Notably, gender differences in development patterns necessitate a separate examination of boys and girls. To address this knowledge gap, a cross-sectional study was conducted to investigate the potential association between eating behaviors and muscle strength in male adolescents.

2. Methods

2.1 Participants

Data were obtained from the physical-education examinations of final semester male students of six local high schools in Jiangsu Province, China. The total number of boys in these high schools was approximately 5230. These high schools were randomly selected through random sampling, and selection of specific classes. All the high school students of these schools participated in the physical-education examination. An accompanying questionnaire having a comprehensive study description was distributed among all participants. All students voluntarily provided their written consent to participate in the study. The study was approved by the ethics committee of the Huaiyin Institute of Technology and was conducted by expert physical-education teachers and instructors who had undergone rigorous training. Students unable to engage in physical exercise due to illness or disability were excluded, as were those who had provided incomplete or inaccurate data in the questionnaire or physical fitness tests (n = 189). The final sample comprised 1916 boys, and the participation rate was 91.0%.

2.2 Eating behaviors

The eating behavior of the participants was explored using a self-report questionnaire that featured two main aspects: breakfast consumption and late-night eating. To evaluate the frequency of breakfast consumption, the participants were required to respond to the following question: "In the past month, how many days per week did you eat breakfast?" [15]. To assess the frequency of late-night eating, participants had to respond to the question: "In the past month, how many days per week did you eat dinner 2 h before sleeping?" [16]. For both questions, the response options ranged from "never" to "7 days per week" and the participants had to choose the frequency best matching their eating habits. The responses were grouped into three categories: low, medium and high. For breakfast consumption, 0–3, 4–6 and 7 days per week were named as "low", "medium" and "high" frequencies, respectively. For late-night eating, 0, 1–3 and 4–7 days per week were named as "low", "medium" and "high" frequencies, respectively. Unhealthy eating behaviors were defined as skipping breakfast or eating dinner 2 h before sleeping on one or more days weekly. The number of unhealthy eating behaviors was named as "none" (without unhealthy eating behavior), "one" (with one unhealthy eating behavior), or "two" (with two unhealthy eating behaviors).

2.3 Muscle strength

2.3.1 Grip strength (upper body strength)

Muscle strength was evaluated by measuring grip strength using a dynamometer (EH 101, Yingling Co., Shanghai, China). Two measurements were taken for each hand, and the maximum force applied was used for the analysis. The participants were instructed to stand upright with their arms straight down squeezing the handle of the dynamometer as hard as possible. The measurements were conducted twice for each hand to obtain an accurate grip-strength reading.

2.3.2 Standing long jump (lower body strength)

Lower body strength was assessed using the standing long jump test in an indoor sports facility. The participants were instructed to stand behind a marked line and execute a two-foot takeoff and landing while generating forward momentum by arm swinging and knee bending. The measurement was taken from the take-off line to the nearest point of contact on landing, specifically at the back of the heels. Two attempts were performed, and the longest jump distance (cm) was used for the analysis. This method has been previously employed to assess lower body power [17, 18].

2.4 Confounding factors

The body weight and height of the participants were measured to calculate the body mass index (BMI), by dividing the weight by the square of the height (kg/m^2). Physical activity level was evaluated using the International Physical Activity Questionnaire (IPAQ) [19], which helped measure the total daily physical activity in metabolic equivalents of tasks $\times$ hours per week. The participants were categorized into low, medium or high levels of physical activity groups based on IPAQ scores. Depression was assessed using the Zung Self-Rating Depression Scale [20] and a score of 50 or above indicated the depression [21]. Further information, including age (a continuous variable); race (Han and minority); living area (urban and rural); family structure (two parents and other, one child and other); living status (at home and other); and living expenses (low, medium or high), was collected using a self-report questionnaire.

2.5 Statistical analysis

Descriptive statistics are shown as values of the mean with 95% confidence intervals (CIs) for continuous variables and percentages for category variables. The differences between the categories of eating behaviors were studied using analysis of variance for continuous variables and chi-square tests for category variables. The relationship between eating behaviors and muscle strength was studies by analysis of covariance (ANCOVA) using the adjusted models. The eating behaviors were categorized into tertiles and treated as independent variables while muscle strength was a dependent variable. Model 1 was adjusted for age, race and BMI; model 2 included adjustments for the variables in model 1, as well as living area, living expenses, family structure, physical activity, living status and depressive symptoms. Statistical analyses were performed using SPSS statistical software (version 24.0) for

Macintosh (SPSS Inc., Chicago, IL, USA). The mean values and CIs (95%) were reported, and the *p*-values for linear trends were calculated using the categories. Statistical significance was at $p < 0.05$.

3. Results

Table 1 lists the descriptive statistics of the participants. The mean age and BMI were 16.7 and 21.7, respectively. Among the adolescents, 49.6% took breakfast daily, and 33.7% did not eat late-night. Unhealthy eating was reported by 23.6%, 36.1% and 40.3% of the participants as none, one and two, respectively. The mean grip strength was 33.5 ± 6.3 kg, and the mean standing long jump distance was 220.6 ± 14.5 cm.

TABLE 1. Basic characteristics of participants.

Variable	Mean ± SD or percentage
n	1916
Age (yr)	16.7 ± 0.8
Body mass index (kg/m^2)	21.7 ± 3.8
Minority race (%)	0.7
Physical activity (%)	
Low	22.8
Medium	38.5
High	38.7
Living status (home; %)	75.6
Living area (city; %)	49.6
Family structure (%)	
Double-parent family	92.0
One-child family	49.9
Living expenses (%)	
Low	33.8
Medium	41.9
High	24.3
Depressive symptoms (%)	18.6
Frequency of breakfast consumption (%)	
Low	28.5
Medium	21.9
High	49.6
Frequency of late-night eating (%)	
Low	33.7
Medium	38.9
High	27.5
Number of unhealthy eating behavior (%)	
None	23.6
One	36.1
Two	40.3
Grip strength (kg)	33.5 ± 3.8
Standing long jump (cm)	220.6 ± 14.5

SD: Standard Deviation.

The characteristics of the participants, categorized according to the eating behavior, are detailed in Table 2. Participants who frequently consumed breakfast were older, having higher physical activity, were one-child families, with higher living expenses and exhibited higher muscle strength. Participants with a higher frequency of late-night eating had lower BMIs and physical activity, from double-parent families with more than one child at home, with lower living expenses and lower grip strength. Participants with a higher number of unhealthy eating behaviors were younger, having lower BMIs, engaged in lower levels of physical activity, from families with more than one child at home, with lower living expenses, experiencing depression and exhibited lower muscle strength.

Table 3 presents the correlation between eating behaviors and muscle strength in adolescents, accounting for confounding factors through adjustment. In model 1, the grip strength values for participants with low, medium and high frequencies of late-night eating behaviors were 34.3 (33.8, 34.8); 33.0 (32.5, 33.4); and 33.2 (32.6, 33.7), respectively ($p = 0.002$). An inverse association was observed in model 2 ($p = 0.008$). Breakfast consumption was significantly associated with grip strength. In model 1, the grip strength values for participants with low, medium and high frequencies of breakfast consumption were 32.6 (32.1, 33.1); 32.7 (32.1, 33.3); and 34.3 (33.9, 34.7), respectively ($p < 0.001$). This significant association remained unchanged in model 2 ($p = 0.001$). However, no significant relationship was observed between eating behaviors and the standing long jump distance.

The adjusted association between the number of unhealthy eating behaviors and muscle strength is shown in Table 4. The mean grip-strength values for participants with no, one and two unhealthy eating behaviors were 34.8 (34.3, 35.4); 33.7 (33.2, 34.1); and 32.6 (32.1, 33.0), respectively, with a significant decreasing trend ($p < 0.001$) observed in models 1 and 2. Furthermore, a higher number of unhealthy eating behaviors was associated with lower standing long jump distances in models 1 and 2, with $p = 0.004$ and 0.026, respectively.

4. Discussion

This study revealed a significant positive relationship between healthy eating behaviors and increased muscle strength in male adolescents. The study accounted for diverse covariates, including fundamental demographic details, health status and lifestyle. A strong correlation was observed between healthy dietary habits and higher muscle strength. To the best of our knowledge, this is the first investigation establishing a correlation between late-night eating and muscle strength. Adolescents with frequent unhealthy eating behaviors had lower muscle strength. These results indicate a relationship between eating behaviors and physical fitness, suggesting that unhealthy dietary habits contribute to decreased muscle strength.

Previous studies have demonstrated the relationship between eating behaviors and muscle strength. Notably, these studies primarily examined the relationship among dietary patterns, specific foods, nutritional intake and muscle strength [22–24], which differs from the aim of the present study. Various cross-sectional studies have investigated the relationship between breakfast consumption and muscle strength in adults. For instance, a study on 1415 adult

TABLE 2. Characteristics of participants according to eating behaviors[a].

	Breakfast consumption		Late-night eating		Unhealthy eating behaviors	
	Low	High	Low	High	None	Two
n	546	950	645	526	452	773
Age (yr)	16.5 (16.5, 16.6)[b]	16.7 (16.7, 16.8)*	16.7 (16.6, 16.8)	16.7 (16.6, 16.7)	16.7 (16.7, 16.8)	16.6 (16.5, 16.6)*
BMI (kg/m^2)	21.6 (21.3, 22.0)	21.9 (21.6, 22.1)	21.9 (21.7, 22.2)	21.5 (21.1, 21.8)*	22.2 (21.8, 22.5)	21.6 (21.3, 21.8)*
Minority race (%)	0.1	0.4	0.5	0.2	1.3	0.3*
PA (%)						
Low	38.8	10.7*	14.0	23.6*	8.8	36.9*
Medium	33.0	39.6*	40.8	36.5	40.0	36.2*
High	28.2	49.7*	45.3	39.9*	51.1	26.9*
Living status (home; %)	80.4	73.1*	68.8	83.3*	67.5	79.7*
Living area (city; %)	51.8	48.9	46.5	49.4	45.4	50.5
Family structure						
Double-parent family (%)	92.7	91.6	90.2	94.1*	90.5	93.1
One-child family (%)	40.7	58.7*	57.1	49.4*	61.3	39.8*
Living expenses (%)						
Low	39.4	29.3*	28.5	35.6*	26.1	39.3*
Medium	47.6	38.3*	37.2	44.1*	35.8	46.7*
High	13.0	32.4*	34.3	20.3*	38.1	14.0*
Depressive symptoms (%)	27.1	14.3*	14	19.4*	11.5	23.7*
Grip strength (kg)	32.6 (32.0, 33.1)	34.4 (34.0, 34.7)*	34.3 (33.9, 34.8)	33.2 (32.6, 33.7)*	34.9 (34.3, 35.5)	32.5 (32.1, 33.0)*
Standing long jump (cm)	219.7 (218.4, 220.9)	221.4 (220.5, 222.4)*	221.6 (220.5, 222.7)	220.6 (219.3, 221.8)	222.1 (220.8, 223.5)	219.5 (218.5, 220.6)*

*[a]: Obtained from ANOVA for continuous variables and chi-square test for proportional variables. [b]: Mean; 95% CI in parentheses (all such values). BMI: body mass index. PA: physical activity. *: p for trend < 0.05.*

TABLE 3. Association between eating behaviors and muscle strength among male students.

	n	Grip strength		Standing long jump	
		Model 1[a]	Model 2[b]	Model 1[a]	Model 2[b]
Frequency of late-night eating					
Low	645	34.3 (33.8, 34.8)[c]	34.1 (33.7, 34.6)	221.5 (220.4, 222.7)	221.4 (220.3, 222.5)
Medium	745	33.0 (32.5, 33.4)	33.2 (32.7, 33.6)	219.7 (218.6, 220.7)	219.9 (218.8, 220.9)
High	526	33.2 (32.6, 33.7)	33.2 (32.6, 33.7)	220.6 (219.4, 221.8)	220.5 (219.3, 221.8)
p for trend[d]		0.002	0.008	0.264	0.303
Frequency of breakfast consumption					
Low	546	32.6 (32.1, 33.1)	32.9 (32.3, 33.4)	219.7 (218.5, 220.9)	220.0 (218.7, 221.2)
Medium	420	32.7 (32.1, 33.3)	32.9 (32.3, 33.5)	219.8 (218.4, 221.1)	219.9 (218.5, 221.3)
High	950	34.3 (33.9, 34.7)	34.1 (33.7, 34.5)	221.4 (220.5, 222.3)	221.2 (220.2, 222.1)
p for trend[d]		<0.001	0.001	0.034	0.158

[a]: Adjusted for age, race, and body mass index. [b]: Adjusted for age, race, body mass index, living area, living expenses, family structure, physical activity, living status, depressive symptoms. [c]: Variables are expressed as estimated geometrics means (95% CI). [d]: Obtained using ANCOVA.

TABLE 4. Association between number of unhealthy eating behaviors and muscle strength among male students.

	n	Grip strength		Standing long jump	
		Model 1[a]	Model 2[b]	Model 1[a]	Model 2[b]
Number of unhealthy eating behaviors					
None	452	34.8 (34.3, 35.4)[c]	34.6 (34.0, 35.2)	222.1 (220.7, 223.4)	221.9 (220.5, 223.2)
One	691	33.7 (33.2, 34.1)	33.5 (33.1, 34.0)	220.6 (219.6, 221.7)	220.5 (219.4, 221.6)
Two	773	32.6 (32.1, 33.0)	32.8 (32.4, 33.3)	219.6 (218.6, 220.6)	219.8 (218.8, 220.9)
p for trend[d]		<0.001	<0.001	0.004	0.026

[a]: *Adjusted for age, race, and body mass index.* [b]: *Adjusted for age, race, body mass index, living area, living expenses, family structure, physical activity, living status, depressive symptoms.* [c]: *Variables are expressed as estimated geometrics means (95% CI).* [d]: *Obtained using ANCOVA.*

Japanese employees indicated a positive relationship between the frequency of breakfast consumption and muscle strength [13]. Similarly, a cross-sectional study conducted in China involving 2009 adults aged 25–65 revealed that individuals who frequently consumed breakfast and engaged in less post-dinner snacking had increased grip strength [15]. Although the present study partially aligns with these findings, the sample size of current and previous studies is different from each other. Conversely, two studies reported that the practice of skipping breakfast is correlated with decreased physical fitness, including reduced standing long jump distance and grip strength, in Chinese adolescents and university students [14, 18]. Although the participants of the current study and those of the previous studies were of similar age groups, dietary habits other than breakfast consumption were not considered in the previous studies. To the best of our knowledge, the present study is the first to examine the relationship between late-night eating and muscle strength in male adolescents. Another study of 278 French primary school children revealed that decreased physical fitness is associated with unhealthy eating behaviors [12]. This study used the same method as ours to assess unhealthy eating behaviors and reached a similar conclusion. However, the age of the participants and the methodology employed to assess eating behaviors and muscle strength differed.

Contrarily, no significant relationship was observed between skipping breakfast and muscular fitness or speed/agility among European adolescents, suggesting that the effect of breakfast skipping on specific components of physical fitness may vary across different populations [25]. This finding contradicts the results of our study, probably due to the different populations studied and methodologies used. Overall, the present study contributes to the growing body of evidence of the relationship between eating behaviors and muscle strength, particularly in adolescent populations.

The negative effects of unhealthy eating behaviors may lead to decreased muscle strength owing to the impact on physical activity. Previous studies [11] suggest a lower frequency of breakfast consumption with reduced physical activity, whereas a higher frequency of breakfast consumption is associated with increased levels of physical activity. Considering the importance of physical activity for improving physical fitness, the significance of breakfast consumption in promoting physical well-being has been established [26]. Skipping breakfast was strongly linked to late-night eating (r = −0.204), and both behaviors are known to influence sleep patterns [27, 28]. Sleep is important for building muscle strength and recovery from fatigue [29]; therefore, eating behaviors may affect muscle strength independently or in combination with other behaviors. Furthermore, skipping breakfast has been correlated with reduced protein and energy intake [30, 31], leading to physical inactivity and reduced muscle strength. Energy and nutrition play vital roles in the strengthening of muscles [32].

Although the present study establishes the relationship between eating behaviors and muscle strength in male adolescents, the study has its limitations. First, the eating behaviors study relied on self-reported data, which may have been influenced by recall bias. Similarly, breakfast consumption and late-night eating were solely assessed as proxies for eating behaviors, thereby overlooking meal quality and other eating behaviors, such as binge eating, eating outside the home and skipping meals. This may have influenced the relationship between unhealthy dietary habits and muscle strength. Second, the study was confined to a particular population of high school students in Jiangsu Province, which may constrain the external validity of the present findings to other cohorts and geographic regions of Chinese adolescents. Further research using a larger and more diverse sample across different Chinese regions is necessary to confirm the generalizability of the results. Third, owing to the cross-sectional design of the study, it was impossible to establish causal relationships. Therefore, it's unclear whether healthier dietary habits lead to higher muscle strength or if higher muscle strength leads to the adoption of healthier dietary habits. Finally, despite multivariate analysis with the inclusion of covariates, the possibility of unmeasured confounders and residual bias can't be eliminated from the study. The absence of information on various lifestyle factors, nutritional covariates, and comorbidities may have influenced the outcome.

5. Conclusions

This study suggested a significant association between healthy dietary habits and enhanced muscle strength in male adolescents. Specifically, participants who regularly consumed breakfast, had a lower frequency of late-night eating, and limited unhealthy eating behaviors exhibited better muscle

strength. These results highlight the importance of promoting healthy dietary habits among adolescents to improve their physical fitness. Thus, regular breakfast consumption should be encouraged, discouraging late-night eating and reducing the number of unhealthy eating behaviors. These findings have significant implications for health education and preventive medicine. However, further interventional or prospective studies are required to establish the causal relationships between dietary habits and muscle strength.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

DWY and TLW—designed the research study. YJL, DWY, QZ and WL—performed the research. WL and CQZ—provided help and advice on validation and manuscript preparing. YJL, DWY and TLW—analyzed the data. YJL, TLW and CQZ—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethical Committee of the Huaiyin Institute of Technology (2019RL-22). All the students voluntarily provided written consent to participate in this study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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