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Longitudinal study on the impact of public health event control measures on physical fitness among Chinese adolescents: a southern city perspective

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Abstract

Since the World Health Organization declared COVID-19 no longer a public health emergency in 2023, over a year has passed. However, there has been insufficient research into whether the physical health of adolescents has recovered post-Pandemic. The COVID-19 Pandemic profoundly impacted the lives and health of adolescents globally, with prolonged lockdowns and social isolation measures potentially causing adverse effects on their physical health. This study aims to systematically evaluate the long-term impact of the Pandemic on the physical health of adolescents in a city in southern China. By analyzing data from over 48,000 tests, changes in various physical performance metrics, including Body Mass Index (BMI), Lung Capacity, endurance, speed, flexibility, and strength, were examined before, during, and after the Pandemic.

The findings indicate that during and after the Pandemic, adolescents experienced an increase in BMI, while Lung Capacity and endurance significantly declined. Specifically, the average BMI for both Males and FeMales peaked after the Pandemic. Male Lung Capacity continuously decreased during and after the Pandemic, while FeMales saw a slight increase during the Pandemic but a significant drop afterward. In terms of endurance, male 1000-meter running times increased during the Pandemic and slightly improved afterward; however, female 800-meter running times increased during and after the Pandemic. Speed performance in the 50-meter sprint was best pre-Pandemic, worst during the Pandemic, and showed recovery post-Pandemic. Strength indicators, such as standing long jump, pull-ups (Males), and sit-ups (FeMales), displayed varying degrees of change, reflecting a decline in physical strength during the Pandemic. Additionally, flexibility improved throughout the period, peaking post-Pandemic.

The study reveals the complex and multifaceted effects of Pandemic control measures on adolescent physical health. These findings are crucial for informing future public health policies and interventions aimed at supporting adolescent health during crises. The novelty of this research lies in its comprehensive and quantitative analysis of the Pandemic's impact on various physical health metrics, providing valuable insights for subsequent studies and policy formulation.

Keywords Adolescent health, Physical fitness, COVID-19 pandemic, Longitudinal study, Body Mass Index (BMI)

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Introduction

It is well established that physical activity is crucial for the healthy development of adolescents during their formative years [1]. However, since the outbreak of the COVID-19 virus in the fall of 2019, Chinese adolescents have faced prolonged periods of social distancing policies and quarantine measures, significantly reducing their participation in group outdoor activities and sports [2]. These restrictions have had detrimental effects on their physical health, including issues such as increased obesity, stunted growth, and reduced cardiorespiratory fitness [3].

During the Pandemic, despite enforced social isolation and the cessation of in-person physical education classes at schools, measures such as participating in online physical education classes were implemented to mitigate these effects [4]. By the end of 2023, China finally declared the COVID-19 Pandemic no longer a public health emergency, ending three years of nationwide isolation and control policies [5]. However, the long-term impact of these measures on the physical health of adolescents, post-Pandemic, remains inadequately explored [6].

To understand the changes in physical fitness among Chinese adolescents under Pandemic control measures, this study was conducted in a southern city of China. The research sampled physical fitness data of adolescents aged 17 to 21, monitoring data from before, during, and three years after the outbreak, spanning ages 19 to 24, with continuous participation in physical fitness assessments [7]. This study aims to uncover how the Pandemic has affected the physical development of this generation of Chinese adolescents and analyze their recovery post-Pandemic, with the hope of disseminating findings globally for future research and discussion.

During the COVID-19 Pandemic, extensive control measures were implemented globally, significantly impacting the physical and mental health of individuals across all age groups. While numerous studies have focused on the effects of these measures on adults, research on adolescents remains relatively scarce. Adolescents, due to their developmental stage, are particularly sensitive to environmental changes, making this an area worthy of thorough investigation [8].

Prior to the COVID-19 Pandemic, studies had already examined the physical health and fitness of adolescents. For example, some research indicated a positive correlation between physical activity and the health of adolescents [9]. However, these studies often overlooked external factors such as the impact of public health crises on adolescent fitness.

During the Pandemic, some studies began to explore the impact of lockdown measures on adolescent health. For instance, research by Wang et al. found that adolescents' physical activity significantly decreased during lockdown, and their body mass index (BMI) increased notably [10]. However, most of these studies focused on Western countries, with limited research on the impact on Chinese adolescents.

There are several gaps in the current body of research. Firstly, there is a lack of longitudinal studies on the changes in fitness among Chinese adolescents during the Pandemic. Most existing studies are cross-sectional and fail to capture the trends in fitness before, during, and after the Pandemic. Secondly, current research primarily focuses on single indicators like BMI, lacking a comprehensive assessment of physical fitness that includes Lung Capacity, running performance, etc. [11].

This study fills the aforementioned gaps and holds significant academic and practical value. Firstly, this study employs a longitudinal design to systematically evaluate the changes in fitness among adolescents in a southern Chinese city before, during, and after the Pandemic. Secondly, we use a comprehensive set of fitness assessment indicators, including BMI, Lung Capacity, 50-meter sprint, 800-meter run (FeMales)/1000-meter run (Males), sit-and-reach, standing long jump, pull-ups (Males)/sit-ups (FeMales) [12]. The diversity and comprehensiveness of these data enhance the reliability and applicability of our findings.

By integrating various fitness indicators, this study not only reveals the impact of Pandemic control measures on adolescent fitness but also provides empirical evidence for future public health policy-making. We found that the overall fitness level of adolescents declined during the Pandemic, with recovery varying by gender and specific fitness components [13]. These findings offer guidance for schools and parents on how to effectively improve adolescent fitness in the post-Pandemic era.

Method

Subjects

Data were obtained from the 2019, 2020, and 2021 waves of the Chinese National Survey on Students' Constitution and Health (CNSSCH), similar as Li [14] a joint project of the Ministries of Education, Health, Science and Technology, the State Ethnic Affairs Commission, and the State Sports General Administration of the People's Republic of China. After data cleaning, the study ultimately obtained a sample size of over 16,000 individuals, comprising approximately 50,000 data points. This dataset includes 16,285 data points from before the Pandemic, 16,567 during the Pandemic, and 16,961 after the Pandemic.

```python
from sklearn.svm import SVR
from sklearn.model_selection import train_test_split
from sklearn.metrics import mean_squared_error

# Assume X is the feature matrix and y is the target vector
# X contains the results of fitness test parameters, y represents the years
# X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, r

# Initialize the SVR model
svm_regressor = SVR(kernel='rbf')  # Selecting the radial basis function ker

# Train the model
svm_regressor.fit(X_train, y_train)

# Predict
y_pred = svm_regressor.predict(X_test)

# Evaluate the model
mse = mean_squared_error(y_test, y_pred)
print("Mean Squared Error:", mse)
```

Fig. 1 Schematic diagram of SVR support vector machine regression process steps in python

Inclusion criteria

The participants in the study were aged between 17 and 21 at the time of testing, and they fully participated in physical fitness assessments conducted before, during, and after the Pandemic.

Exclusion criteria

Adolescents aged 17–21 participated in one or two rounds of physical fitness testing before, during, and after the Pandemic, but did not complete all three rounds of testing.

Calculation

The study employed random sampling to investigate physical fitness monitoring data of adolescents aged 17–21 in a southern Chinese city before, during, and after the Pandemic. Data were imported into SPSS 26.0 (IBM Corp) for paired samples t-test analysis and descriptive statistics. Prior to these analyses, the normality distribution of the results was assessed using the Shapiro-Wilk test. Additionally, a support vector machine (SVM) model was utilized in Python to regressive analyze the linear trends of the data and conduct training and learning; the specific Python code is shown in detail in Fig. 1 below.

Reasons for method selection

Support Vector Machine (SVM) was chosen due to its strengths in handling high-dimensional, multidimensional data, effectively capturing complex nonlinear relationships among physical fitness indicators like BMI and endurance. SVM's robustness minimizes overfitting, ensuring reliable results.

Applicability and superiority of SVM

SVM surpasses traditional methods (e.g., paired sample t-tests) by simultaneously analyzing interrelationships among multiple indicators, supporting nonlinear classification and regression, and delivering high-precision outcomes.

Results validation

To enhance credibility, paired sample t-tests complement SVM results. This involves conducting t-tests on key fitness indicators to confirm the consistency of findings.

Method transparency

Details on SVM parameter settings (kernel selection, penalty parameters) and the analysis process (data preprocessing, model training) are provided to ensure reproducibility. Code snippets are included for clarity.

Table 1 Physical fitness evaluation categories and their evaluation indices [1]

Evaluation Category	Evaluation Index
Body shape	BMI (weight/height^2)
Respiratory system function	Vital capacity (ml)
Endurance	800-m (female)/1000-m (Males)
Speed	50 m sprint (s)
Flexibility	Sit and reach (cm)
Body strength	Standing long jump (cm)
	Pull-ups (Males)/Timed sit-ups (FeMales)

Indicators and measurement methods

The study involves a vast dataset, analyzing results from over 48,000 tests. Each dataset includes the following items: BMI, Lung Capacity, 800 m run(for FeMales) /1000m run (for Males), 50 m sprint, Sit-and-reach, Standing long jump, Pull-ups (for Males) /Sit-ups (for FeMales), detailed test items and classification are shown in Table 1 below.

Measuring instruments and procedures

The following instruments and methods were utilized for the fitness assessments:

Height and Weight Measurement:

Height was measured using infrared detection technology.
Weight was recorded using scales connected to computers.

Body Mass Index (BMI) was calculated using the formula:

$$\text{weight (KG)} \div \text{height 2(M)}$$

Timed Tests:

Timers and starting devices were used for running tests to ensure accurate timing.

Physical Fitness Tests:

Standing Long Jump: Conducted on a standardized jumping mat. Participants performed a maximal forward jump, with measurements taken from the take-off line to the nearest landing mark.
Pull-Ups (Males) and Timed Sit-Ups (FeMales): These tests were performed using specialized equipment, with manual checks for accuracy.
Sit-and-Reach Test: Measured using a sit-and-reach box, ensuring consistent positioning for each participant.

Human involvement in the testing process was primarily for teaching and verifying accuracy.

Results

Descriptive analysis

The analysis results are divided into three sections: overall results, results for Males, and results for FeMales.

Body shape

From a temporal perspective, the obesity rate among Chinese adolescents was lowest before the Pandemic. The BMI values for the overall group, Males, and FeMales were 20.15, 20.84, and 19.56, respectively, before the Pandemic. During the Pandemic, BMI values increased to 20.31 for the overall group, 21.03 for Males, and 19.79 for FeMales. After the Pandemic, these values reached their peak at 20.45 for the overall group, 21.22 for Males, and 19.90 for FeMales. The specific development trend has been visualized in the Fig. 2 below.

Respiratory system function and endurance

Lung Capacity and endurance performance among Chinese adolescents showed a synchronous decline over time. Before the Pandemic, adolescents demonstrated better Lung Capacity and endurance than during or after the Pandemic, Lung Capacity's Overall: Before the Pandemic, the average Lung Capacity was 3230.87 mL. This decreased to 3201.52 mL during the Pandemic and further declined to 3091.11 ml, after the Pandemic, Males: The Lung Capacity was 3935.96 mL before the Pandemic, dropped to 3900.06 mL during the Pandemic, and decreased to 3799.59 mL post-Pandemic, FeMales: Before the Pandemic, the Lung Capacity was 2630.40 mL. During the Pandemic, it increased slightly to 2700.82 mL, but post-Pandemic, it decreased to 2590.81 mL. The specific development trend has been visualized in the Fig. 3 below.

Endurance Running Times: 1000 m (for Males): The average time to complete 1000 m was 239.61 s before the Pandemic. This increased to 246.29 s during the Pandemic and then slightly improved to 243.67 s after the Pandemic. The specific development trend has been visualized in the Fig. 4 below.

800 m (for FeMales): The average time for the 800 m was 234.81 s before the Pandemic, increased to 239.76 s during the Pandemic, and further increased to 241.97 s post-Pandemic. The specific development trend has been visualized in the Fig. 5 below.

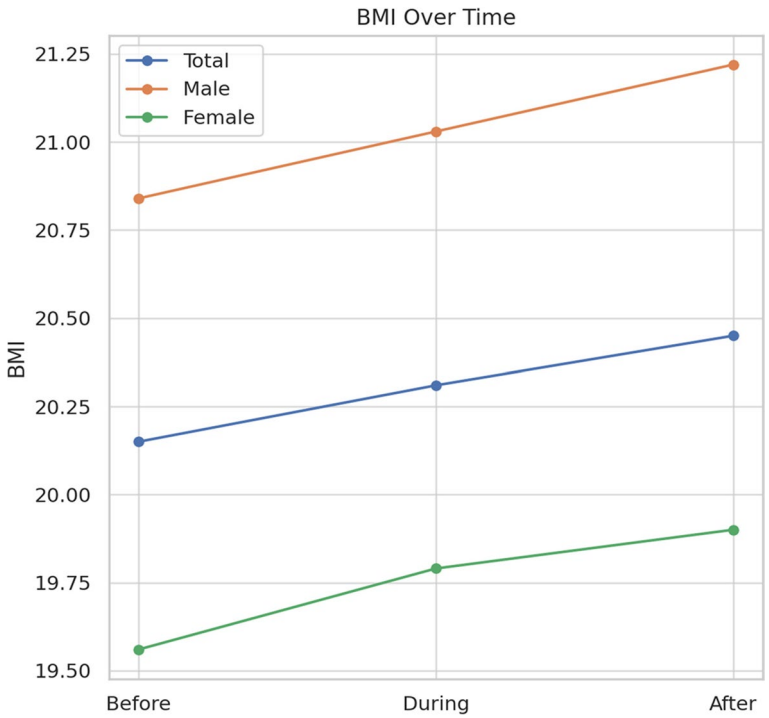

Fig. 2 BMI before, during and after epidemic

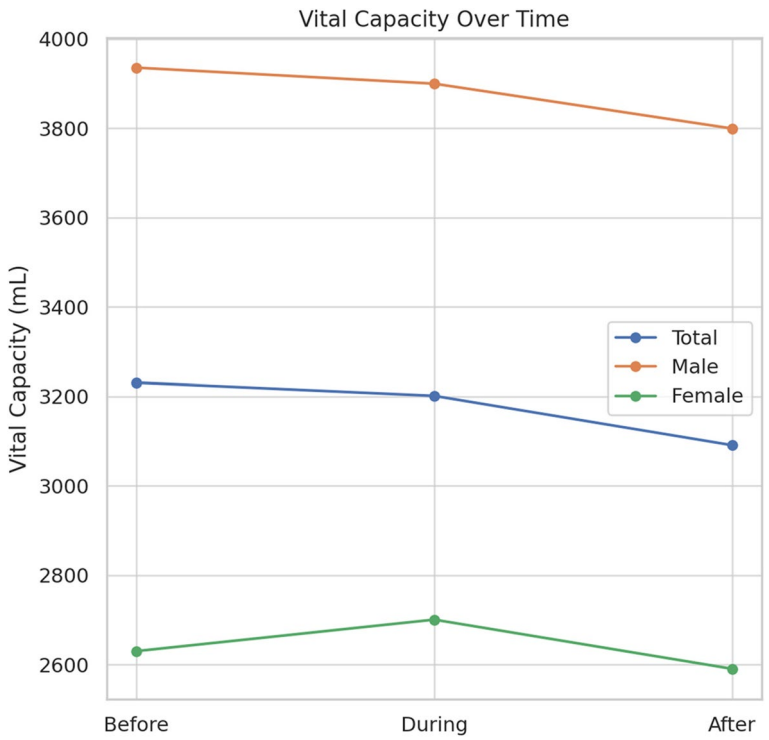

Fig. 3 Vital capacity before, during and after epidemic

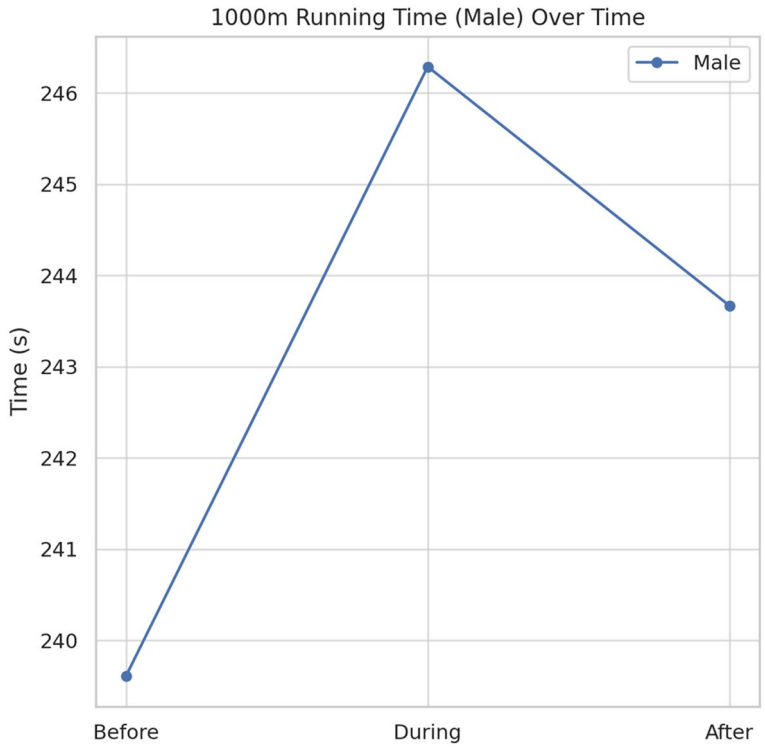

Fig. 4 1000m before, during and after epidemic

Speed

The best performance for the 50-meter sprint among adolescents was observed before the Pandemic. The statistical values for overall, Males, and FeMales were 8.48 s, 7.61 s, and 9.21 s, respectively. However, the worst performance occurred during the Pandemic, with the values increasing to 8.81 s overall, 7.82 s for Males, and 9.52 s for FeMales. After the Pandemic, there was a slight improvement in performance, with the values recorded at 8.77 s overall, 7.77 s for Males, and 9.48 s for FeMales. This pattern suggests that the physical restrictions during the Pandemic significantly affected sprinting performance, but some recovery was noted once the restrictions were lifted. The specific development trend has been visualized in the Fig. 6 below.

Body strength

Strength is assessed through three indicators: standing long jump, pull-ups (for Males), and sit-ups (for FeMales). For the standing long jump, the values remained fairly consistent across the different periods: Overall: 182.1 cm (pre-Pandemic) → 178.90 cm (during the Pandemic) → 182.84 cm (post-Pandemic). Males: 210.09 cm (pre-Pandemic) → 209.96 cm (during the Pandemic) → 210.65 cm (post-Pandemic). FeMales: 158.27 cm (pre-Pandemic) → 156.65 cm (during the Pandemic) → 158.96 cm (post-Pandemic). The specific development trend has been visualized in the Fig. 7 below.

The values for pull-ups and sit-ups showed a steady decline: Pull-Ups (Males): 10.99 repetitions (pre-Pandemic) → 10.49 repetitions (during the Pandemic) → 10.01 repetitions (post-Pandemic). The specific development trend has been visualized in the Fig. 8 below.

Sit-Ups (FeMales): 39.16 repetitions (pre-Pandemic) → 36.25 repetitions (during the Pandemic) → 36.10 repetitions (post-Pandemic). The specific development trend has been visualized in the Fig. 9 below.

Flexibility

Flexibility showed an improving trend over time. The values for overall, Males, and FeMales were as follows: Pre-Pandemic: Overall: 13.26 cm, Males: 11.97 cm, FeMales: 14.36 cm. During the Pandemic: Overall: 15.95 cm, Males: 14.61 cm, FeMales: 16.92 cm. Post-Pandemic: Overall: 16.2 cm (peak value), Males: 14.5 cm (slightly decreased), FeMales: 17.4 cm (peak value). Overall and female flexibility values continued to improve throughout the period, reaching their highest levels post-Pandemic. However, male flexibility values slightly declined after reaching their peak during the Pandemic. The specific development trend has been visualized in the Fig. 10 below.

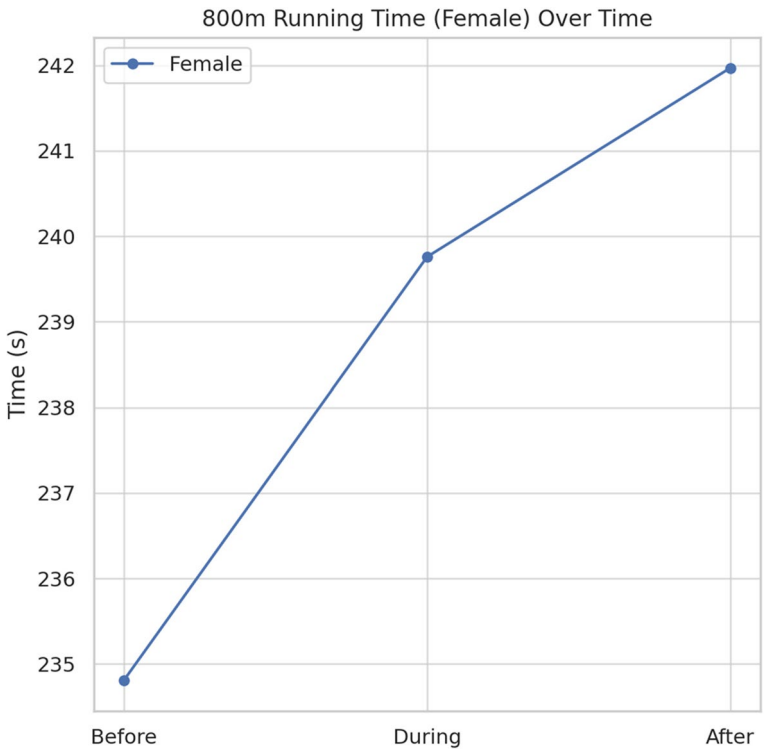

Fig. 5 800m before, during and after epidemic

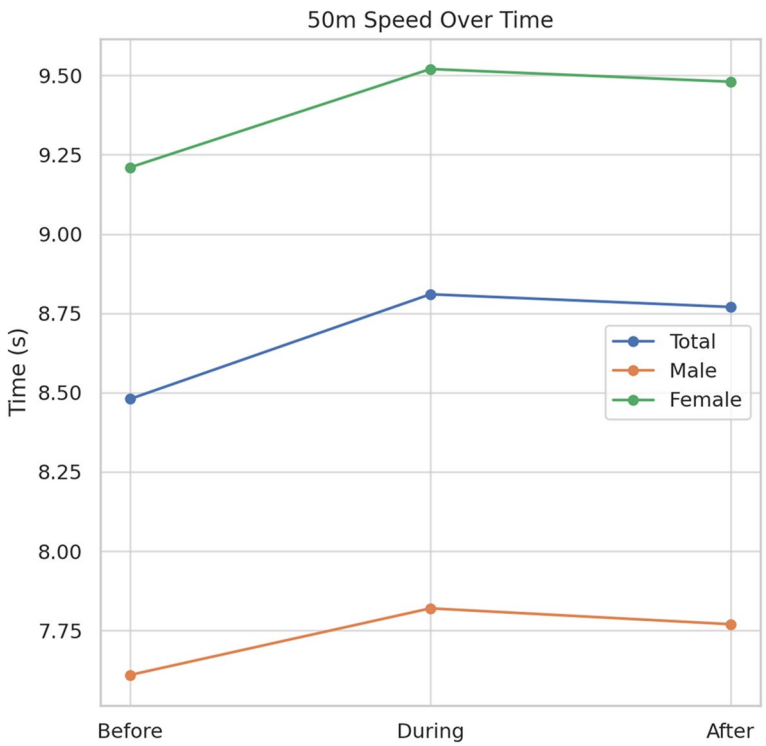

Fig. 6 50m before, during and after epidemic

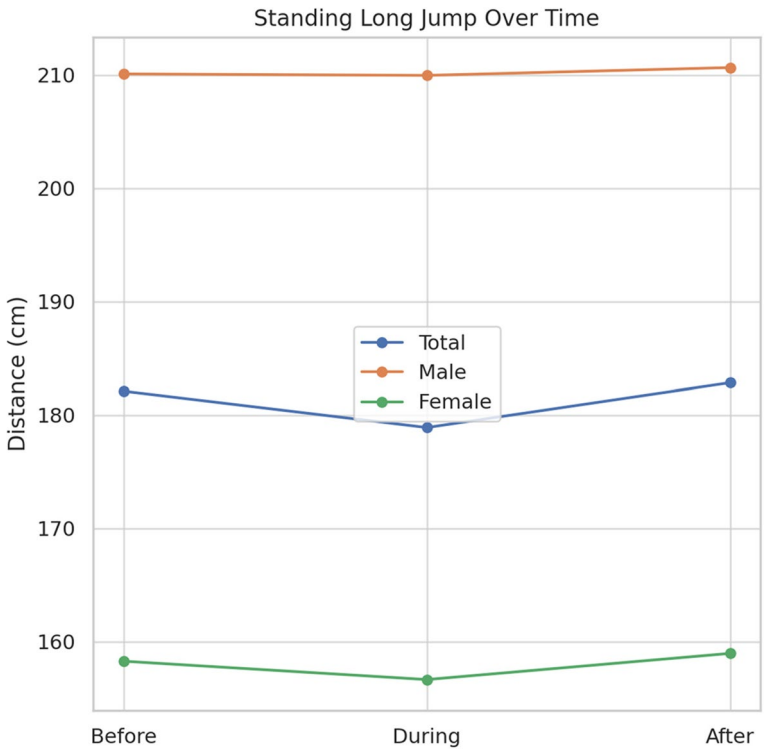

Fig. 7 Standing long jump before, during and after epidemic

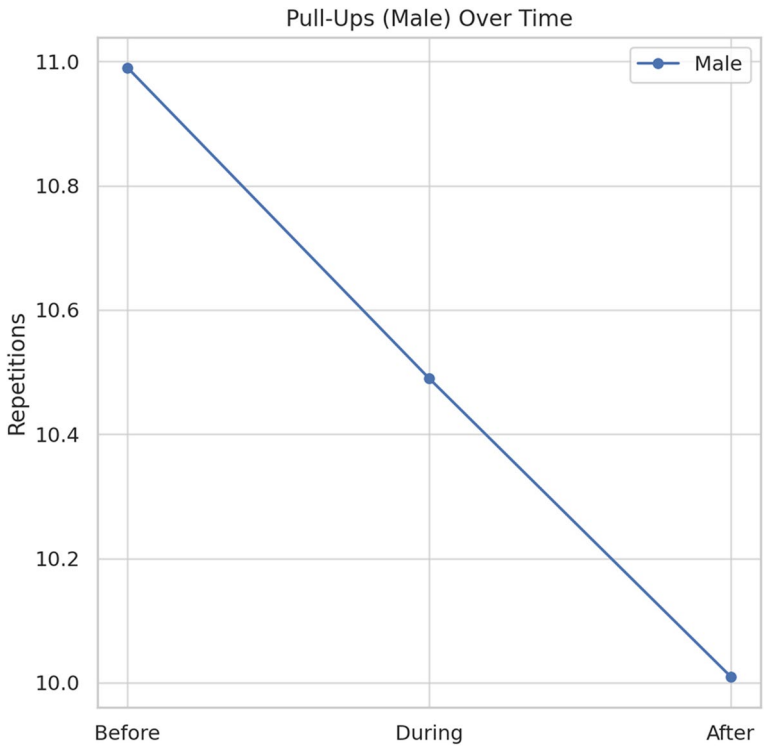

Fig. 8 Pull-ups before, during and after epidemic

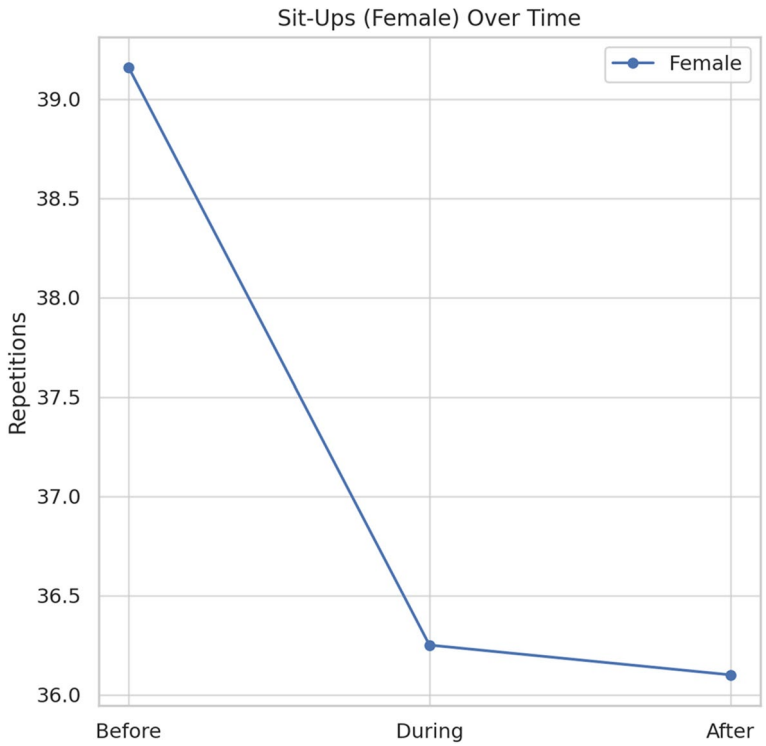

Fig. 9 Sit-ups before, during and after epidemic

SVM (support vector machine) analysis results

The study involved importing 49,813 data points into Python for analysis. The data for Males and FeMales were distributed as follows: Before the Pandemic: nMales: 7,490, FeMales: 8,795. During the Pandemic: Males: 6,917, FeMales: 9,650. After the Pandemic: Males: 7,020, FeMales: 9,941. The total dataset comprised 43.00% male and 56.99% female data, indicating a reasonably balanced distribution. After setting up the SVM (Support Vector Machine) [15] model, the machine learning process began to analyze the development patterns of physical fitness data. The SVM regression analysis revealed that the p-values for the pre-set significance tests were all less than 0.05, indicating statistically significant regression results. The findings showed several trends among adolescents in this city over the three periods (before, during, and after the Pandemic): BMI: There was a year-on-year increase in BMI values. Lung Capacity and Aerobic Endurance: Both declined each year. Strength (Pull-Ups for Males and Sit-Ups for FeMales): There was a continuous decrease over time. 50-Meter Sprint and Standing Long Jump: Performance declined during the Pandemic but showed improvement after the Pandemic ended. Flexibility (Sit-and-Reach): The values showed consistent improvement each year. These trends underscore the impact of the Pandemic on various aspects of physical fitness among adolescents. Specific calculation results have been displayed in Tables 2, 3 and 4 below.

Discussion

During the COVID-19 Pandemic, numerous studies have focused on the physical health of adolescents. Some research indicates that the Chinese government implemented online physical education classes to prevent the deterioration of student fitness. However, these efforts were found to be insufficient to maintain adequate physical activity levels [16]. A review of previous studies reveals that scholars have varied perspectives on the impact of China's preventive measures on the population's physical health during the Pandemic [17].

Diverse perspectives on pandemic impact

Permanent vs. Temporary Effects: Some studies argue that the harm caused by COVID-19 infections is permanent, whereas the decline in physical fitness due to lack of exercise is temporary [18]. Importance of Exercise in Adolescents: Other research emphasizes that physical activity is crucial during adolescence, and the lack of exercise during the Pandemic has had severe consequences on this age group's development [19].

Despite differing viewpoints, it is widely acknowledged that the physical health of adolescents is a significant

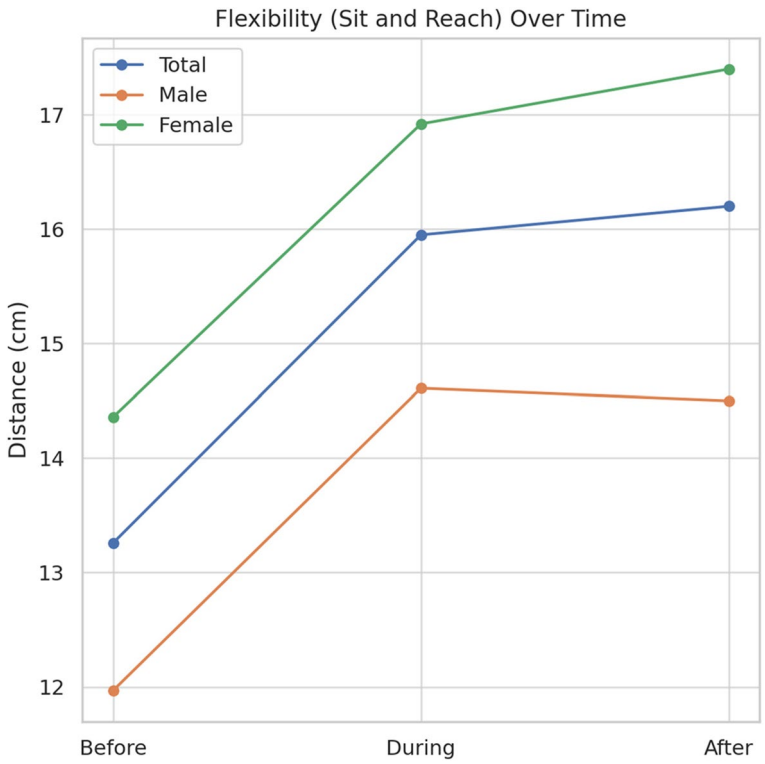

Fig. 10 Sit and reach before, during and after epidemic

Table 2 The variance results of total youths

	Total (mean ± SD)			F	*p*
	Before(*n* = 16285)	During(*n* = 16567)	After(*n* = 16961)		
BMI	20.15 ± 2.75	20.31 ± 2.83	20.45 ± 2.85	46.125	0.000**
50 m	8.48 ± 1.22	8.81 ± 1.24	8.77 ± 1.10	387.952	0.000**
Standing long jump	182.10 ± 34.57	178.90 ± 35.20	182.84 ± 35.63	58.982	0.000**
Sit and reach	13.26 ± 9.15	15.95 ± 7.93	16.20 ± 7.40	654.206	0.000**
Vital capacity	3230.87 ± 930.69	3201.52 ± 853.52	3091.11 ± 827.17	119.8	0.000**
800 m (s)	234.81 ± 20.26	239.76 ± 22.23	241.97 ± 24.34	246.844	0.000**
1000 m(s)	239.61 ± 24.98	246.29 ± 26.31	243.67 ± 20.26	142.271	0.000**
Sit-up	39.16 ± 7.81	36.25 ± 8.54	36.10 ± 8.30	398.517	0.000**
Pull-up	10.99 ± 4.25	10.49 ± 5.21	10.01 ± 5.61	68.845	0.000**

** $p < 0.01$

concern [20]. Post-Pandemic, many have explored and researched the health issues faced by adolescents [21]. However, there remains a shortage of longitudinal studies that track changes in adolescent physical fitness across the pre-Pandemic, Pandemic, and post-Pandemic periods. This study aims to fill this gap by providing data-driven insights into the physical fitness trends among Chinese adolescents during these periods.

BMI trends

The analysis shows a sharp increase in BMI values among Chinese university students following the COVID-19 Pandemic. The lowest BMI values were recorded before the Pandemic, with a notable rise during and after the Pandemic [22]. This deviates from the normal developmental trajectory, as previous research suggests that BMI typically decreases gradually in adolescents aged

Table 3 The variance results of male youths

	Men (mean ± SD)			F	*p*
	Before($n=16285$)	During($n=16567$)	After($n=16961$)		
BMI	20.84 ± 2.95	21.03 ± 3.10	21.22 ± 2.99	28.263	0.000**
50 m	7.61 ± 0.82	7.82 ± 0.80	7.77 ± 0.60	153.446	0.000**
Standing long jump	210.09 ± 25.05	209.96 ± 26.33	216.65 ± 24.26	163.237	0.000**
Sit and reach	11.97 ± 9.36	14.61 ± 8.32	14.50 ± 7.66	225.444	0.000**
Vital capacity	3935.96 ± 778.78	3900.06 ± 744.73	3799.59 ± 682.57	65.868	0.000**
1000 m(s)	239.61 ± 24.98	246.29 ± 26.31	243.67 ± 20.26	142.271	0.000**
Pull-up	10.99 ± 4.25	10.49 ± 5.21	10.01 ± 5.61	68.845	0.000**

** $p<0.01$

Table 4 The variance results of female youths

	Women (mean ± SD)			F	*p*
	Before($n=16285$)	During($n=16567$)	After($n=16961$)		
BMI	19.56 ± 2.41	19.79 ± 2.50	19.90 ± 2.61	43.979	0.000**
50 m	9.21 ± 1.01	9.52 ± 0.98	9.48 ± 0.78	296.811	0.000**
Standing long jump	158.27 ± 21.06	156.65 ± 21.08	158.96 ± 19.32	32.717	0.000**
Sit and reach	14.36 ± 8.82	16.92 ± 7.50	17.40 ± 6.96	406.185	0.000**
Vital capacity	2630.40 ± 550.82	2700.82 ± 502.66	2590.81 ± 483.35	115.673	0.000**
800 m (s)	234.81 ± 20.26	239.76 ± 22.23	241.97 ± 24.34	246.844	0.000**
Sit-up	39.16 ± 7.81	36.25 ± 8.54	36.10 ± 8.30	398.517	0.000**

** $p<0.01$

17–21. The increase in BMI may be attributed to reduced physical activity due to social distancing measures and increased nutritional intake aimed at bolstering immunity against the virus.

Lung capacity and aerobic endurance

Lung Capacity among Chinese youth showed a continuous decline across all three testing periods, which is inconsistent with typical human development. The study posits two potential causes for this trend: Prolonged social isolation policies [23]. Possible long-term effects of COVID-19 infection on lung function, contributing to reduced Lung Capacity [21].

Running and explosive power

The best endurance running results (for both 1000 m and 800 m) were recorded before the Pandemic. These metrics reached their lowest point during the Pandemic but improved somewhat post-Pandemic. Similar trends were observed in the 50-meter sprint and standing long jump tests, indicating that the Pandemic adversely affected adolescents' running and explosive power abilities.

Body strength and flexibility

Body strength and flexibility demonstrated contrasting trends. Due to insufficient exercise, muscle strength (as measured by pull-ups for Males and sit-ups for FeMales) continuously declined, while flexibility improved over time. This aligns with previous research findings, suggesting that while muscles atrophy from lack of use, flexibility can increase due to the reduced muscle tightness associated with inactivity [24].

These results highlight the multifaceted impact of the COVID-19 Pandemic on adolescent physical health, underscoring the importance of continued research and intervention to address these changes. By integrating various fitness indicators, this study not only reveals the impact of Pandemic control measures on adolescent fitness but also provides empirical evidence for future public health policy-making. Our research primarily examines changes in the physical fitness status of adolescents during the pandemic, revealing a notable decline in overall fitness levels, with variations by gender and specific fitness components [16].

While we do not provide direct guidelines for improving fitness, our findings lay the groundwork for future interventions. By highlighting the specific areas of decline, this study can inform schools and parents about the need for targeted strategies to support adolescent fitness recovery in the post-pandemic period.

Conclusion

Through analyzing and comparing the physical fitness test data of Chinese adolescents before, during, and after the COVID-19 outbreak, this study concludes that adolescent physical fitness has been significantly affected by the Pandemic. Even one year after the comprehensive lifting of social distancing measures, the impact of these policies on adolescents' physical fitness continues, with their fitness levels not fully recovering to pre-Pandemic levels. Key Findings: Pre-Pandemic Fitness Levels: Before the outbreak, Chinese adolescents exhibited the highest levels of physical fitness, with the highest test scores. Post-Pandemic Changes: One year after the end of the outbreak, the following changes in adolescent physical fitness were observed: Continued Increase in Obesity Rates: Obesity rates have continued to rise without showing signs of decline. Persistent Decline in Cardiopulmonary Function: Cardiopulmonary function has continued to decline without recovery. Endurance and Explosive Power: Long-distance running ability and explosive power showed some recovery after the end of isolation measures but did not exceed pre-Pandemic levels. Muscle Atrophy and Flexibility: Muscle atrophy led to a continuous decline in strength, while flexibility continued to improve. Impact of Social Isolation Policies: Despite the Chinese government's efforts to minimize COVID-19 risks, social isolation policies inevitably caused significant health disruptions among adolescents. Persistent Health Impacts: Even one year after the Pandemic ended, these serious health effects have not naturally improved. Chinese adolescents still face health risks that may warrant enhanced interventions in physical education and health. This study underscores the enduring impact of COVID-19 and highlights the ongoing need for targeted health interventions to support the physical well-being of adolescents in China.

Limitation

This study's data were potentially influenced by regional cultural factors. While participants came from various provinces and cities across China, they fundamentally represent a Chinese demographic, suggesting some limitations in generalizability. The study utilized a template based on China's student physical fitness tests and did not specifically design experiments or select indicators to address the potential impacts of COVID-19. It is entirely based on quantitative research, potentially lacking in qualitative aspects. Future research could supplement this by focusing on qualitative components to provide a more comprehensive understanding.

Abbreviations

COVID-19	Coronavirus disease 2019
BMI	Body Mass Index
SVM	Support vector machine
SVR	Support vector regression
M	Mean
SD	Standard Deviation
P	Probability
F	Equality of Variances

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-20751-y.

Supplementary Material 1.

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Authors' contributions

Dr. Chao Zhou (C.Z), initiated and provided financial support for the study. Dr. Chao Zhou (C.Z) collected and compiled all the data, wrote and reviewed each part of the research, and completed the study with Aowei Zhang (A.W.Z). And Aowei Zhang (A.W.Z) as the principal investigator. All authors reviewed the manuscript.

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Data availability

No datasets were generated in this study. All datasets can be obtain by official websites: the Ministry of Education, Ministry of Health, Ministry of Science and Technology, State Ethnic Affairs Commission, and the General Administration of Sport of the People's Republic of China jointly conducted the National Student Physical and Health Surveys in 2019, 2020, and 2021, and have published all datasets. Requests for he analyzed datasets by this study may be made to Aowei Zhang; please send an email to zhangaowei_012t@luohuedu.net .

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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