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# Association between Olympic Games and children's growth: evidence from China

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**ABSTRACT****Objectives** To estimate the association between the 2008 Beijing Olympic Games (BOG) and growth of children in China.**Methods** A total sample of 6 951 children aged 3–10 years were included, among which 3 201 were interviewed in 2014 and 3 750 were interviewed in 2018. The BOG was used as a natural experiment. Exposure to the BOG was established by triple differences measured by age group, survey period and whether child participants were living in BOG areas or not, respectively. Children's growth was assessed by binary variables of stunting, underweight, overweight and obesity. The difference-in-difference-in-differences (DDD) method was used to estimate the association between the BOG and children's growth.**Results** DDD estimates showed that the BOG was significantly associated with decreased risks of children's underweight (OR 0.12; 95% CI 0.02 to 0.69) and overweight (OR 0.43; 95% CI 0.19 to 0.98) after controlling for multiple covariates in fractional polynomial models. There was significant sex heterogeneity with regard to the association between BOG and obesity, that is, lower odds of obesity (OR 0.24; 95% CI 0.06 to 0.94) were found in female children but not in male children.**Conclusion** The BOG was positively associated with healthier growth of children including decreased risks of both undernutrition and overnutrition. More attention should be given to the improvement of health surveillance and services before and after sporting events so that the active role of such mega-events in the lasting well-being of the public can be determined in more detail.**INTRODUCTION**

Shortly after the Tokyo Olympic Games, the Beijing Winter Olympic Games and Paralympic Games have been held in February 2022. Previously, public health experts have expressed great concerns over the safety of the Tokyo Olympic Games amid the COVID-19 pandemic and appealed for a global conversation on it.<sup>1</sup> Although mass gatherings have potential risks amid a global health crisis, the legacy of health concepts, services and facilities of the Games with well public health preparedness might contribute to population health in which they are hosted, including children's growth. In fact, in addition to political benefits, economic growth, urban boosterism and sports infrastructure, the public health legacy like the promotion of public health services and risk management,<sup>2</sup> the enhancement of public health surveillance and reporting systems,<sup>3</sup> the improvement of external hygienic environment and enhancement of health consciousness and behaviours of individuals,<sup>4</sup> is of

greater concern to the host of the Olympic Games and other mega-events.

Previous studies have especially indicated that compared with the pre-Olympic Games periods, PM10 (population-weighted respirable particulate matter with an aerodynamic diameter less than 10 µm) exposure during the Beijing Olympic Games (BOG) came down by 46%<sup>5</sup> and the black carbon concentration on Olympic days was dramatically reduced due to the traffic control regulations.<sup>6</sup> Lots of research have shown that exposure to air pollution could be harmful to children's growth<sup>7–9</sup> and thus the improvement of air quality during the BOG may positively contribute to the development of children. Additionally, the short-term and medium-term associations between Olympic Games and mental health of individuals were suggested by a previous study in which adolescents who were "no longer depressed" (risk ratio 1.53, 95% CI 1.07 to 2.20) at 6 months were more likely to come from the intervention borough that had urban regeneration due to the 2012 London Olympic Games.<sup>10</sup> The interactions and interdependency between mental health and child growth problems, especially overweight and obesity, have also received a lot of attention and evidence from researchers.<sup>11 12</sup> The previous findings above indicated the potential positive role that Olympic Games may serve in the growth of children. However, the direct long-term association between Olympic Games and growth of children has yet to be well examined.

The present study, using the BOG as a natural experiment, was designed to capture the potential long-term association of Olympic Games and children's growth at the population level via the difference-in-difference-in-differences (DDD) method, established by examining the regional variations of Olympic Games exposure across age groups and survey periods. The investigation of the relationship between the BOG after SARS and health can provide implications for the follow-up influence of the Beijing Winter Olympic Games during this epidemic given that both games were held in China, although there are differences in the type of Olympic Games and the status of the pandemics. This research will also help us to assess the association of the Olympic Games and children's growth more comprehensively.

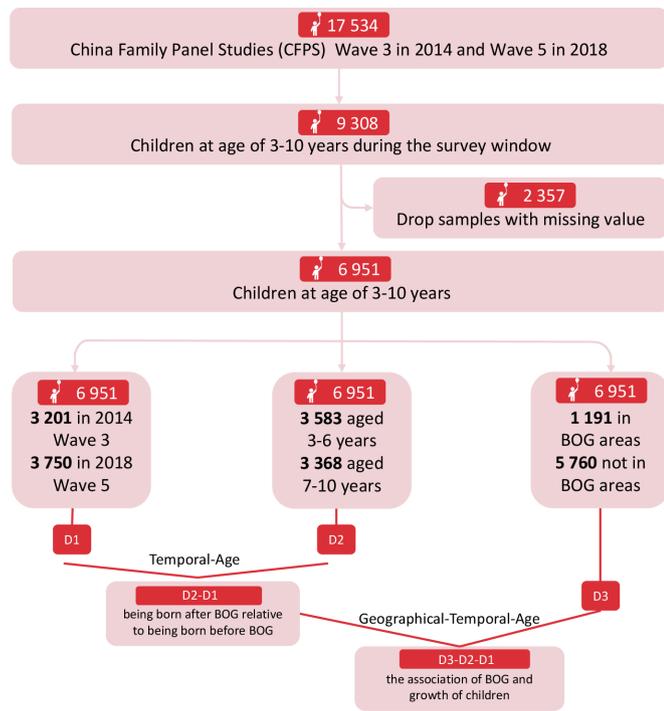
**METHODS****Study design and data sources**

We used the existence of the 2008 BOG in China as a natural experiment since it is exogenous for any individual and is suitable to obtain an appropriate counterfactual condition to estimate its influence. Individual-level data were obtained from the China



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**Figure 1** Flow chart of samples. BOG, Beijing Olympic Games.

Family Panel Studies (CFPS). CFPS is a national, comprehensive, longitudinal survey conducted from 2010 that aims to collect a wide range of information of the Chinese society, economy, population, education and health.<sup>13</sup> Using multistage probability proportional to size sampling with implicit stratification, a total of 33 600 adults and 8 990 youths from 14 960 households in 25 provinces or their administrative equivalents in China were interviewed in the baseline national survey in 2010. Then, four follow-up surveys were done in 2012, 2014, 2016 and 2018. Additional details of the survey design including sampling method can be found in the previous work of CFPS team.<sup>14 15</sup> For this study, we created panel data with a sample of children aged 3–10 years at the survey time from the CFPS wave 3 done in 2014 and wave 5 in 2018. A total of 6 951 cases were included in the analysis. **Figure 1** illustrates the derivation of our analytical sample.

### Exposures

In the current study, exposure to the BOG was measured by triple differences:

First, children aged 7–10 years during the survey window were identified as the treated group, who were born (during 2004–2007) before the BOG in CFPS wave 2014, and born (during 2008–2011) after the BOG in wave 2018. Children aged 3–6 years were identified as the control group, who were born after the BOG in both wave 2014 (born during 2008–2011) and wave 2018 (born during 2012–2015). The difference of the control group between two waves (D1) could be identified as the temporal changes caused by macro-environmental development, and the difference of the treated group between two waves (D2) included the variation of being born after the BOG relative to being born before the BOG in addition to the temporal changes. Then, the variation caused by being born after the BOG relative to being born before the BOG can be identified through the difference between treated group and control group in difference between two waves (D2–D1).

Additionally, although the Olympic Games is an event with national and even world implications, we assume that its association with children's growth is mainly reflected in the population living in the venue of the Games and its surrounding areas. The host city of the 2008 BOG is Beijing, with five mainland cities: Shanghai, Tianjin, Shenyang of Liaoning province, Qinhuangdao of Hebei province and Qingdao of Shandong province, as co-host cities (Hong Kong was also a co-host city but not included in our analysis due to data limitation). Thus, we categorised the areas where our child participants were living across provinces of mainland China into a binary variable (BOG areas or non-BOG areas). Since children aged 3–6 years and children aged 7–10 years may grow at different rates, the D2–D1 estimator mentioned above did not control the trend differential between the treated group and control group. However, the trend differential of children of any one age group in the BOG areas and in non-BOG areas could be similar. Thus, the association between the BOG and children's growth could be identified through the difference between areas in difference between age groups in difference between waves (D3–D2–D1).

In other words, we estimated the association between the BOG and children's growth by comparing the variations of outcomes across triple BOG-related differences including the age groups, periods and living areas where the children were investigated. Then, based on the logic expressed above, the change in children's growth related to the BOG event beyond the individual background trends can then be estimated using the DDD analysis as the superposition of the above triple differences.

### Outcomes

The outcomes of this study are four indicators for children's growth, that is, stunting or not, underweight or not, overweight or not and obesity or not. First, height and weight of children aged 3–9 years were reported by their families and children aged 10 years self-reported their height and weight given they already knew themselves well. Then, we generated standardising anthropometric measures in children including z score of height-for-age (HAZ) and z score of weight-for-age (WAZ) according to the WHO growth charts,<sup>16 17</sup> and derived indices of stunting if  $HAZ < -2$  and underweight if  $WAZ < -2$ , respectively. Furthermore, overweight and obesity were measured by binary variables according to the international cut-off points of body mass index (BMI) for children aged 2–18 years.

### Covariate

Difference-in-difference model can provide unbiased estimates with covariates that vary differently over time in the treated and control group or have a time-varying effect on the outcome appropriately adjusted.<sup>18</sup> Thus, confounders in this study include both time-varying covariates such as the age (1 year per group), residence (rural or urban), household economic status (below or above average, based on the annual household income per capita) during the survey window, as well as covariates with time-varying effects on the outcomes including sex (male or female), birth weight (kg) and gestational age (months) of child participants as well as the squared birth weight and squared gestational age, and the education level (primary school and below, or middle school and above), advanced maternal age (yes if higher than 35 years, otherwise not) and registered residence (rural or urban) of the mother of child participants.

## Statistical analyses

We employed the DDD method, which compared the outcomes after and before an event between the treatment and comparison groups as well as another exposure variation within samples. Usually, DDD is implemented as an interaction term between dummy variables of the differences in a regression model. In the presented study, logit regression models for stunting, underweight, overweight and obesity, with DDD estimator, were obtained from:

$$\ln\left(\frac{p}{1-p}\right) = \alpha + \beta dA \times dP \times dB + \gamma_1 dA \times dP + \gamma_2 dA \times dB + \gamma_3 dP \times dB + \delta_1 dA + \delta_2 dP + \delta_3 dB + \varepsilon X$$

Let  $p = P(y=1|x)$  denote the probability of children having certain growth outcome given the predictors,  $dA$  is a dummy for age group,  $dP$  is the dummy for survey period,  $dB$  is the dummy for living in the BOG areas or not,  $X$  denotes the covariates if any and  $\alpha$  is the intercept; where  $\beta$ , the coefficient of the interaction between age groups, living areas and periods, is the DDD estimate of the average association between the BOG and children's growth outcomes.

Cluster-robust SEs and inverse probability weighting were used in each model of the main analysis. The cluster variable is the primary sampling unit (subdistricts for Shanghai and districts for other provinces). The weight variable is cross-sectional weight (individual level) for total sample generated by the data release team of the survey. We first calculated the crude estimators without covariates and then adjusted the estimators by controlling for covariates mentioned above. Additionally, we first fitted the logit regressions with all the covariates based on linearity assumption and then especially controlled for quantitative predictors including birth weight and gestational age using fractional polynomial models with all other covariates remained. The potential heterogeneity across population of the BOG effect was examined by fitting the same models to the female sample and male sample, respectively. The OR, adjusted OR and 95% CIs were calculated. A two-sided  $p$  value of less than 0.05 was identified as statistically significant in this study. STATA V.16 (STATA, College Station, Texas, USA) was used for data analysis.

## RESULTS

### Characteristics of the study participants

The study consisted of 6 951 Chinese child participants at the age of 3–10 years, among which 3 201 were interviewed in 2014 and 3 750 were interviewed in 2018. Among the children, 48.45% were at the age of 7–10 years when interviewed, 53.58% were boys, 56.98% resided in rural areas. A total of 17.13% of the participants were living in BOG areas. Table 1 shows the descriptive statistics of the characteristics of the study participants by survey periods.

### The association between the BOG and stunting, underweight, overweight and obesity of children

Among the analysed children, the prevalence rates of stunting, underweight, overweight and obesity were 7.80%, 26.36%, 14.10% and 20.89%. The prevalence rates of the above four indicators by single difference from age groups, survey period or BOG areas were shown in figure 2A.

Figure 2B presents the DDD estimates of the association between the BOG and stunting, underweight, overweight and obesity of children. We found BOG exposure was significantly associated with decreased risk of children's underweight (OR 0.12, 95% CI 0.02 to 0.69) and overweight (OR 0.42; 95% CI 0.18 to 0.98) after controlling for multiple covariates. The

**Table 1** Characteristics of participants

Characteristics	Total	2014	2018
Total sample (n)	6 951	3 201	3 750
Age group, n (%)			
3–6 years	3 583 (51.55)	1 703 (53.20)	1 880 (50.13)
7–10 years	3 368 (48.45)	1 498 (46.80)	1 870 (49.87)
BOG areas, n (%)			
Yes	1 191 (17.13)	661 (20.65)	530 (14.13)
No	5 760 (82.87)	2 540 (79.35)	3 220 (85.87)
Sex, n (%)			
Female	3 227 (46.42)	1 491 (46.58)	1 736 (46.29)
Male	3 724 (53.58)	1 710 (53.42)	2 014 (53.71)
Residence, n (%)			
Rural	3 961 (56.98)	1 871 (58.45)	2 090 (55.73)
Urban	2 990 (43.02)	1 330 (41.55)	1 660 (44.27)
Mother's education, n (%)			
Primary school and below	2 374 (34.15)	1 265 (39.52)	1 109 (29.57)
Middle school and above	4 577 (65.85)	1 936 (60.48)	2 641 (70.43)
Household economic status, n (%)			
Below average	3 396 (48.86)	1 554 (48.55)	1 842 (49.12)
Above average	3 555 (51.14)	1 647 (51.45)	1 908 (50.88)
Mother with advanced maternal age, n (%)			
Yes	1 925 (27.69)	950 (29.68)	975 (26.00)
No	5 026 (72.31)	2 251 (70.32)	2 775 (74.00)
Mother's residence, n (%)			
Rural	5 463 (78.59)	2 422 (75.66)	3 041 (81.09)
Urban	1 488 (21.41)	779 (24.34)	709 (18.91)
Mean (SD) birth weight (kg)	3.237 (0.55)	3.237 (0.55)	3.237 (0.55)
Mean (SD) gestational age (months)	9.380 (0.64)	9.321 (0.64)	9.430 (0.64)

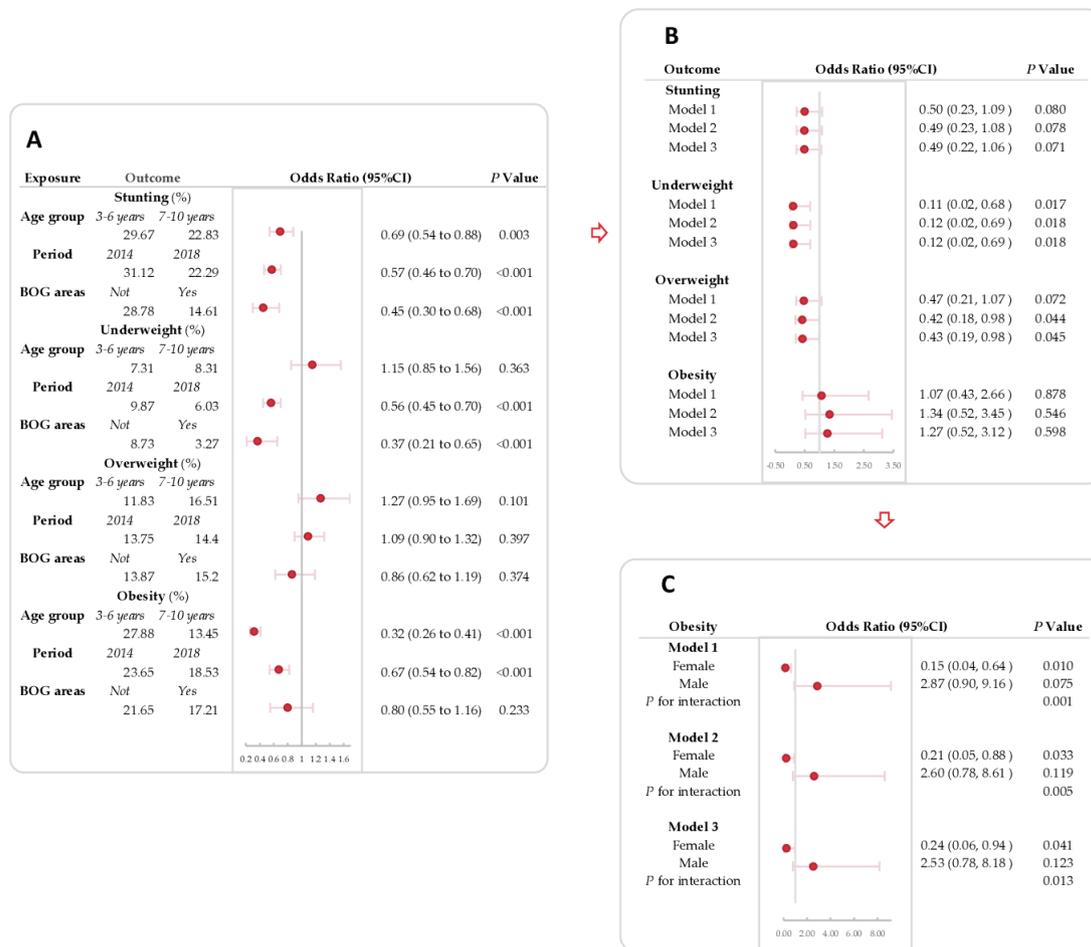
BOG, Beijing Olympic Games.

association between being exposed to the BOG and odds of stunting and obesity was not statistically significant. Results by fractional polynomials were similar for the four growth outcomes of children, that is, a significant decreased risk of underweight (OR 0.12; 95% CI 0.02 to 0.69) and overweight (OR 0.43; 95% CI 0.19 to 0.98) associated with BOG exposure was found.

We did not find any significant sex heterogeneity of associations between the BOG and stunting, underweight or overweight ( $p$  for interaction  $>0.05$ ). However, there was significant sex heterogeneity ( $p$  for interaction  $<0.05$ ) with regard to the association between the BOG and child obesity, that is, significant lower risk of obesity was found in female sample (OR 0.24; 95% CI 0.06 to 0.94 in fractional polynomial model) but not in male sample (figure 2C).

## DISCUSSION

With the change of lifestyle, concerns over the growth of children, including both undernutrition and overnutrition, are intensifying. The present study found that the BOG had positive association with children's growth by decreasing risks of underweight and overweight through the DDD method after eliminating the confounding effects of covariates. In other words, the findings indicated that the BOG may have roles in decreasing the risk of both maldevelopment and overdevelopment of children. Previous studies have investigated the association of Olympic Games and public health such as exposure to respirable particulate matter and adolescent psychological health.<sup>5 6 10</sup> The findings of our study contribute to the literature by proving the first direct evidence of the long-term health associations of sporting mega-events and growth of children from a nationwide perspective and further enriching the scope of the public health legacy of Olympic Games on individuals.



**Figure 2** The association between BOG and children's growth. (A) Prevalence of stunting, underweight, overweight and obesity by single exposure; (B) the association between BOG and stunting/underweight/overweight/obesity of children: results of DDD; (C) sex heterogeneity of the association between BOG and obesity of children: results of DDD. Model 1: logit regressions without controlling covariates; model 2: logit regressions controlling covariates including age, sex, residence, mother's education level, household income per capita, mother with advanced maternal age, mother's residence, birth weight, squared birth weight, gestational age of children and squared gestational age of children; model 3: logit regressions especially controlling for quantitative predictors including birth weight and gestational age using fractional polynomial models with all other covariates remained. BOG, Beijing Olympic Games; DDD, difference-in-difference-in-differences.

There are many factors that may be associated with the growth of children, among which Olympic Games, as the largest and most influential sports event in the world, may play a significant role through the following potential mechanisms. On one hand, children of the Olympic generation would benefit from a variety of good conditions during the fetal period related to Olympic Games just like the mechanism of the fetal origin's hypothesis.<sup>19</sup> According to an official publication of the IOC,<sup>20</sup> the Games left a positive legacy for China in social, urban, environmental, athletic, economic aspects and so on, such as the improvement of air, food and water safety, the regeneration of community physical environment, the smoke-free actions and the increase in venues and training facilities which promoted mass sport. Empirical studies also demonstrated that the BOG positively affected the environmental efficiency in Beijing and co-host cities, but without significant effect in neighbouring cities.<sup>21</sup> All of these are conducive to mothers-to-be exposed to the BOG because they stay in the healthy environment and maintain healthy behaviours such as exercise, nutrition and smoking control, in order to achieve good pre-pregnancy and prenatal conditions for their offspring. There is a considerable body of evidence that shows that risk of underweight or obesity was lower among

offspring whose mothers maintained a healthy BMI, engaged in regular physical exercise and did not smoke.<sup>22-25</sup>

On the other hand, the positive legacy of the Games mentioned above in healthy behaviours and services may play a mediating role in the pathway of the relationship of the BOG and children's growth. Most directly, the Games may promote the enthusiasm and action of individual sports participation through the centralised publicity of sports in a short period of time, and even cultivate long-term family sports atmosphere and habits.<sup>26</sup> For example, the prevalence of physical activity or sports participation increased significantly after the BOG.<sup>27</sup> Additionally, family physical activity environment and parental-based interventions, alone or with their child, especially adherence to a healthy lifestyle in mothers during their offspring's childhood and adolescence, were reported to be significantly related to child weight management and a substantially reduced risk of overweight or obesity.<sup>23 28 29</sup> Moreover, the Games have increased the Olympic values education and improved the attention to physical training in Chinese schools, and a large number of primary and secondary schools have opened up their sports facilities to the public,<sup>22</sup> which may also increase the possibility and accessibility of exercise for children after school, alone or together with their families. School-based physical activities are proven beneficial to the

obesity prevention or treatment for children with overweight,<sup>30</sup> and physical activities after school are also reported to result in positive improvements in children's weight outcomes<sup>31</sup> to avoid underweight. Notably, previous studies indicated that Chinese boys had higher prevalence of obesity and were more likely to be satisfied with their physical activity level than girls,<sup>32</sup> which may be a potential explanation for the sex difference in the association between the BOG and obesity found in our study.

Our study indicated that the effect of the BOG can be applied to individuals who do not actually participate in the competition, and the Olympic generation children who grow up in the friendly environment built by the legacy of the Games can benefit from it for a long time. It demonstrates that China has taken advantage of the opportunities that the Games provided, not only the economic aspect, but also the public health aspect. In fact, the health legacy is also an important achievement of the Olympic Games conducted after Beijing, such as the increase in fitness activity and the use of facilities especially by children after Vancouver 2010 Winter Olympic Games and the 'Go London' programme developed due to London 2012 Olympic Games that enabled over 200 health and well-being projects and initiatives including the "Healthy Weight" initiative to reduce child obesity in the borough.<sup>33 34</sup> Our findings highlight greater emphasis on the importance of health investment and planning for further mega-events, especially the 2022 Beijing Winter Olympic Games and Paralympic Games. Although we cannot infer this expectation to the Beijing Olympic Winter Games given the differences in seasons, sizes and especially the statuses of pandemic when they were held, we can still expect that the sports atmosphere, health facilities and surveillance left over from the 2022 Games would be positively associated with people's health considering China's strict quarantine measures for this sporting event, such as vaccination, closed loop, test, trace and isolate, minimising physical interaction and so on.<sup>35 36</sup>

This study was subject to some limitations. First, in the absence of birth month of the participants, we speculated the relationship between the birth time of study samples and the time of the BOG only on the scale of year. Second, since the health legacy of the BOG may also benefit those who were born before the BOG during their growth process in later life, the relationship we found in this study could be better understood as the association of Olympic legacy available from the fetal period relative to not being available in such an early period. Third, we did not control some factors in models due to the lack of related information in the data. For example, the hereditary traits of children, healthy behaviours, and the height and weight of their parents may be potential confounders and threaten the robustness of the results. Fourth, height and weight of children reported by their families or themselves may cause reporting bias or recall bias. Additionally, the lower confidence limit of OR of 0.02 for underweight implies the possibility of sparse data bias, which means downward bias with few participants at pivotal combinations of the exposure, outcome and covariates.<sup>37</sup> Moreover, we could only conclude associations while causation could not be fully determined. Despite these limitations, to our best knowledge, as the first study attempting to examine the long-term association of Olympic Games and children's growth, this study contributed uniquely to the knowledge pool regarding the positive spillover effects of sporting mega-events on the growth of children at a large population level on the basis of robust data and methods.

## CONCLUSIONS

In conclusion, the current study highlights that the 2008 BOG was associated with decreased risks of underweight and overweight in children. The findings of this study have important

public health and policy implications. Specifically, governments and organisers of mega-events should pay more attention to long-term health legacy planning, including the complete and thorough assessment of health surveillance and services before and after the Games are held.

## Key messages

### What is already known on this topic?

⇒ Several previous studies investigated the association between Olympic Games and public health such as exposure to respirable particulate matter, adolescent psychological health and asthma, but none studied the long-term association of Olympic Games and child growth.

### What this study adds?

⇒ The 2008 Beijing Olympic Games was associated with decreased risks of underweight and overweight of children.  
 ⇒ Female children appeared to benefit more from the potential preventative role of 2008 Beijing Olympic Games on obesity compared with male counterpart.

### How this study might affect research, practice or policy?

⇒ The host countries of future Olympic Games could carry forward the Olympic health legacy with greater focus on the potential positive effects on childhood growth and development.  
 ⇒ Further studies are needed to follow the public health impacts of Olympic Games in the longer term and throughout the age spectrum.

**Contributors** CG formulated the research questions, designed the study and wrote the first draft of the manuscript. CG and XH analysed the data. CG, XH, CX and XZ contributed to the data interpretation and revising the manuscript. All authors agreed with the results and conclusions of the manuscript and approved the final version. CG is responsible for the overall content as guarantor.

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**Patient and public involvement** Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

**Patient consent for publication** Obtained.

**Ethics approval** This study involves human participants. The survey was reviewed and approved by the Peking University Biomedical Ethics Review Committee (approval number: IRB00001052-14010). Participants gave informed consent to participate in the study before taking part.

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**Data availability statement** Data are available upon reasonable request. This study is based on publicly available datasets, and the data can be accessed from the website: <http://www.issp.pku.edu.cn/cfps/en/data/public/index.htm>.

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