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ORIGINAL RESEARCH

Clustering of Multilevel Factors Among Children and Adolescents: Associations With Health-Related Physical Fitness

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Background: To identify the clustering characteristics of individual-, family-, and school-level factors, and examine their associations with health-related physical fitness. ***Methods:*** A total of 145,893 Chinese children and adolescents aged 9–18 years participated in this cross-sectional study. The 2-step cluster analysis was conducted to identify clusters among individual-, family-, and school-level factors. Physical fitness indicator was calculated through sex- and age-specific *z* scores of forced vital capacity, standing long jump, sit-and-reach flexibility, body muscle strength, endurance running, and body mass index. ***Results:*** Three, 3, and 5 clusters were automatically identified at individual, family, and school levels, respectively. Students with low physical fitness indicator were more likely to be in the "longest sedentary time and skipping breakfast" cluster (odds ratio [OR] = 1.18; 95% confidence interval [CI], 1.12–1.24), and "physical inactivity and insufficient protein consumption" cluster (OR = 1.07; 95% CI, 1.02–1.12) at individual level, the "single children and high parental education level" cluster (OR = 1.15; 95% CI, 1.10–1.21), and "no physical activity support and preference" cluster (OR = 1.30; 95% CI, 1.25–1.36) at family level, and the "physical education occupied" cluster (OR = 1.06; 95% CI, 1.01–1.11), and "insufficient physical education frequency" cluster (OR = 1.16; 95% CI, 1.08–1.24) at school level. Girls were more vulnerable to individual- and school-level clusters, while boys were more susceptible to family clusters; the younger students were more sensitive to school clusters, and the older students were more susceptible to family clusters (*P-interaction* < .05). ***Conclusions:*** This study confirmed different clusters at multilevel factors and proved their associations with health-related physical fitness, thus providing new perspective for developing targeted interventions.

Keywords: cluster analysis, influencing factors, public health, youth

Physical fitness is widely recognized as an important health indicator owing to its role in reflecting motor abilities and physical functions, especially for children and adolescents during their growth and development.[1,2] As a basic component of physical fitness, health-related physical fitness is commonly considered more relevant to physical functions, including measurements of body composition, cardiorespiratory fitness, muscular strength, muscular endurance, and flexibility, which has been applied to fitness tests among school-aged students around the world.[2–4] Importantly, research studies to date have demonstrated that health-related physical fitness is a strong predictor of cardiovascular diseases, skeletal health, cancer, and mental health in childhood and adulthood.[5,6] Evidence has shown that health-related physical fitness levels among children and adolescents have deteriorated globally, demonstrating it has become a public health problem in need of being addressed, and improved, globally.[7,8]

It is imperative to explore the corresponding influencing factors on behalf of ameliorating health-related physical fitness levels among children and adolescents, and to analyze the multilevel factors, and the distribution characteristics with consideration of rapid economic development and lifestyle changes.[3,9] Previous studies have proved the significant associations of individual, family, and school factors with health-related physical fitness among children and adolescents, respectively.[10–15] For example, individual factors including physical inactivity, sedentary behaviors, and unhealthy diets are associated with low health-related physical fitness levels[10,11]; family factors including parental education level and family support also can impact health-related physical fitness level[12,13]; and school factors including physical education (PE), interclass exercise, and school facility provision were observed to be associated with health-related physical fitness as well.[14,15] However, few studies have completely analyzed the association between these influencing factors and health-related physical fitness from an integrated and multilevel perspective.[16]

When considering the theory that unhealthy factors could present simultaneously among children and adolescents, it is important to analyze how influencing factor clusters account for identifying subgroups at greater risk for relevant health problems, and to look more closely at targeted interventions.[17,18] However, as for health-related physical fitness problems among children and adolescents, only a few studies have analyzed the association between clustering of individual lifestyle behaviors and health-related physical fitness, which included small samples and lacked representativeness,[10,11] while no study explored the clustering effect of family- and school-level factors. Therefore, it is necessary to conduct a cluster analysis in the large national sample to allocate individuals into groups according to the similar characteristics of individual-, family-, and school-level factors, respectively, and to evaluate synergetic effects, rather than isolated effects of these factors on health-related physical fitness to understand the risk of each subgroup and to determine more practical implications on effective interventions.[19,20] In addition, it is

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significant to discover subgroup differences on the basis of clustering analysis, contributing to identifying vulnerable groups to be improved, such as gender, age, and urban–rural disparities.

Based on current evidence, we put forward our hypothesis that clustered subgroups from individual, family, and school levels were all associated with health-related physical fitness among children and adolescents, and, in addition, subgroup differences existed. Therefore, we aimed to analyze the clustering characteristic of individual-, family-, and school-level factors, and examine their associations with health-related physical fitness from holistic and grouped perspective, drawing upon a national cross-sectional survey among Chinese children and adolescents in 2019.

Methods

Study Design and Study Sample

Data used by this cross-sectional study were derived from the 2019 Chinese National Survey on Students' Constitution and Health, the largest national survey covering 30 provinces on indicators of health-related physical fitness and multilevel influencing factors among children and adolescents aged 9–18 years. As previously described,[3] this study was conducted using a multistage stratified cluster sampling, divided into 3 stages: first, 3 prefecture-level cities identified by socioeconomic status in each province were randomly selected, with both rural and urban areas identified in each city; second, schools including primary, junior, and senior high schools were randomly selected in each area; and finally, all the students in randomly selected classes by grade in each school were chosen to participate in the survey. The 2019 Chinese National Survey on Students' Constitution and Health has been approved by the Medical Research Ethics Committee of the Peking University Health Science Center after obtaining informed consent from the survey population (No. IRB00001052-19095).

We excluded samples missing key information, or with outliers and finally, included 145,893 Chinese children and adolescents aged 9–18 years (Figure 1). Chi-square tests were performed to discover the differences between primary sample and final sample, with results showing that the proportion of samples aged 9–15 years in final the sample was lower than that in the primary sample (70.5% vs 72.0%, $P < .001$), the reason was only students in grade 4 and above participated in the questionnaire survey, causing some students aged around 9 years to not be included (Supplementary Table S1 [available online]).

Measures

Questionnaire was determined on the premise that consensus was reached among the team members after expert consultations and amendments, including not only basic information on age, sex, school, province, and urban–rural area, but also multilevel contents about individual, family, and school factors. For individual information, students were asked to fill in the times they engaged in moderate to vigorous physical activity (PA), and various sedentary behaviors, and the frequency of having breakfast, eating eggs, drinking milk, and sugar-sweetened beverages. For family information, we asked single-child status, parental education level, parental support for PA, and parental preference for PA, which were all collected by multiple-choice questions. For school information, we again used multiple-choice questions to investigate the number of PE classes, whether PE classes had been occupied, whether interclass exercise had been conducted daily, and whether a sports meeting had been organized annually.[16] The categorizations and response rate of each indicator are shown in Supplementary Table S2 (available online).

Six core items about health-related physical fitness were measured under strict quality control. Specifically, forced vital capacity, standing long jump, sit-and-reach flexibility, height, and weight were tested in all students by the same measurements except body muscle strength and endurance running: for body muscle strength, boys ≤12 years old performed oblique body pull-ups, and boys aged 13–18 years performed pull-ups, while girls of all ages were tested for 1-minute sit-ups. For endurance running, the eight 50-m shuttle run was chosen for children ≤12 years of age, 800-m endurance running was recommended for girls aged 13–18 years, and 1000-m endurance running was determined for boys aged 13–18 years. The specific test methods and processes were described in previous study.[21] As for the calculation, we computed sex- and age-specific z scores to get standardized values for each component, which was calculated as an individual item's value minus the mean, divided by the SD from the sample with same sex and age. Physical fitness indicator (PFI) was then obtained using the following equation: $z_{\text{forced vital capacity}} + z_{\text{standing long jump}} + z_{\text{sit-and-reach flexibility}} + z_{\text{body muscle strength}} + (-z_{\text{endurance running}}) + z_{\text{converted BMI}}$,[16,22] among which body mass index (BMI) was calculated as weight in kilograms, divided by the square of height in meters, and converted BMI was calculated as: $1/(|z_{\text{BMI}}|+1)$,[22] ensuring higher PFI value indicated better level. Finally, we classified PFI into 3 categories by its value as follows: low level (<20th), middle level (20th–80th), and high level (>80th).[16]

Statistical Analysis

We used mean (SD) and t tests, frequency (percentage), and chi-square tests to describe continuous and qualitative variables, respectively. Hot deck imputation was determined to fill in missing data, with background variables set as sex, urban–rural area, grade and school.

The 2-step cluster analysis was conducted to identify clusters among individual-, family-, and school-level factors, respectively. This method is ideal for handling large datasets and can determine the optimal number of clusters depending on a given dataset automatically.[23] Importantly, it enables the input of both continuous and qualitative variables, which applies to this analysis in particular.[23] We set five 5 categories as the maximum number of clusters in light of previous studies[10,11,17] and used silhouette coefficient to evaluate the quality of clustering process.[17] In addition, we randomly sampled 50% of total sample and repeated the same clustering procedure, after which Cohen's kappa (κ) coefficients were applied to assess the agreements.[19] Analysis of variance and chi-square tests by post hoc Bonferroni adjustment were used for pairwise comparisons among continuous and qualitative variables in clusters, respectively. Linear-by-linear tests were used for trend analysis of age and PFI.

Multinomial logistic regression analysis in a generalized linear mixed model was applied to analyze association of PFI with individual-, family-, and school-level clusters, taking the school as the random-effect term. In addition, we constructed interaction terms of age, sex, and urban–rural area to identify the subgroups' differences, among which age was divided into 9–15 years old (compulsory education) and 16–18 years old (noncompulsory education). Moreover, while interaction term was significant, stratified analysis was performed to concretize and explore the difference.

All analyses were performed using IBM SPSS Statistics (version 26.0) and R (version 4.0.5). A 2-tailed P value < .05 was considered statistically significant.

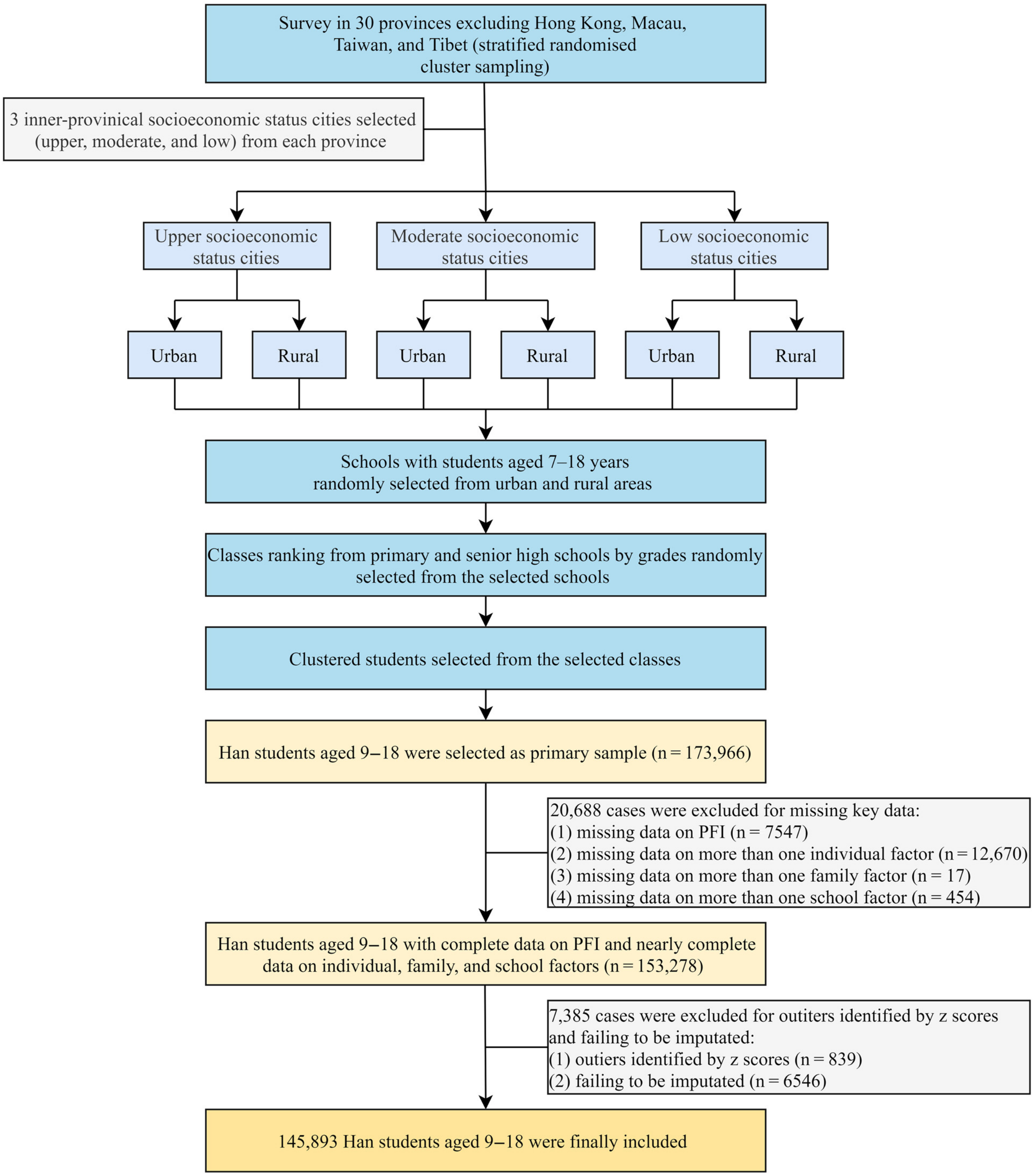

Figure 1 — Flowchart. PFI indicates physical fitness indicator.

Results

Study Participants' Characteristics

Characteristics of the study sample are described in Table 1. A total of 73,134 boys and 72,759 girls were included, with a higher proportion of boys aged 16–18 years, (29.9% vs 29.2%), and from urban areas (50.7% vs 49.9%), respectively. Additionally, all the individual, family, and school factors were unevenly distributed between boys and girls ($P < .05$). Notably, except endurance running ($P < .05$), the z scores of forced vital capacity, standing long jump, sit-and-reach flexibility, body muscle strength, BMI, and PFI were not statistically different between boys and girls ($P > .05$).

Clustering of Individual-, Family-, and School-Level Factors

Individual-, family-, and school-level clusters were shown in Supplementary Tables S3–S5 (available online). The auto-clustering parameters and predictor importance of each variable imputed

Table 1 Characteristics of Study Participants

	Total (N = 145,893)	Boys (n = 73,134)	Girls (n = 72,759)	*P*
Age, y				.005
9–15	102,798 (70.5)	51,284 (70.1)	51,514 (70.8)	
16–18	43,095 (29.5)	21,850 (29.9)	21,245 (29.2)	
Residence				.004
Urban	73,403 (50.3)	37,074 (50.7)	36,329 (49.9)	
Rural	72,490 (49.7)	36,060 (49.3)	36,430 (50.1)	
Individual factors				
MVPA,[a] h/d	0.63 (0.64)	0.70 (0.70)	0.56 (0.57)	<.001
Sedentary time,[a] h/d	7.37 (3.60)	7.43 (3.77)	7.32 (3.41)	<.001
Breakfast				.011
7 d/wk	104,885 (71.9)	52,796 (72.2)	52,089 (71.6)	
<7 d/wk	41,008 (28.1)	20,338 (27.8)	20,670 (28.4)	
Beverages				<.001
<1 time/d	114,905 (78.8)	55,781 (76.3)	59,124 (81.3)	
≥1 times/d	30,988 (21.2)	17,353 (23.7)	13,635 (18.7)	
Egg				<.001
7 d/wk	25,648 (17.6)	14,372 (19.7)	11,276 (15.5)	
<7 d/wk	120,245 (82.4)	58,762 (80.3)	61,483 (84.5)	
Milk				<.001
7 d/wk	47,676 (32.7)	25,285 (34.6)	22,391 (30.8)	
<7 d/wk	98,217 (67.3)	47,849 (65.4)	50,368 (69.2)	
Family factors				
Single-child status				<.001
Yes	59,972 (41.1)	32,666 (44.7)	27,306 (37.5)	
No	85,921 (58.9)	40,468 (55.3)	45,453 (62.5)	
Parental education level				<.001
Primary or below	60,202 (41.3)	29,877 (40.9)	30,325 (41.7)	
Secondary or equivalent	37,808 (25.9)	18,919 (25.9)	18,889 (26.0)	
Junior college or above	47,883 (32.8)	24,338 (33.3)	23,545 (32.4)	
PA support				.011
Yes	114,895 (78.8)	57,396 (78.5)	57,499 (79.0)	
No	30,998 (21.2)	15,738 (21.5)	15,260 (21.0)	
PA preference				<.001
Yes	110,915 (76.0)	54,565 (74.6)	56,350 (77.4)	
No	34,978 (24.0)	18,569 (25.4)	16,409 (22.6)	
School factors				
PE frequency				<.001
≥Twice a week	126,641 (86.8)	62,830 (85.9)	63,811 (87.7)	
<Twice a week	19,252 (13.2)	10,304 (14.1)	8948 (12.3)	
PE occupied				<.001
No	97,170 (66.6)	46,952 (64.2)	50,218 (69.0)	
Yes	48,723 (33.4)	26,182 (35.8)	22,541 (31.0)	
Interclass exercise				<.001
Yes	129,939 (89.1)	64,694 (88.5)	65,245 (89.7)	
No	15,954 (10.9)	8440 (11.5)	7514 (10.3)	
Sports meeting				.013
Yes	128,801 (88.3)	64,414 (88.1)	64,387 (88.5)	
No	17,092 (11.7)	8720 (11.9)	8372 (11.5)	
Health-related physical fitness, *z* scores				
Forced vital capacity[a]	–0.01 (0.97)	–0.01 (0.98)	–0.01 (0.97)	.579
Standing long jump[a]	0.01 (0.99)	0.01 (0.99)	0.01 (0.99)	.590
Sit-and-reach flexibility[a]	0.00 (1.00)	0.00 (1.00)	0.00 (1.00)	.713

(continued)

Table 1 (continued)

	Total (N = 145,893)	Boys (n = 73,134)	Girls (n = 72,759)	*P*
Body muscle strength[a]	–0.02 (0.93)	–0.02 (0.86)	–0.02 (1.00)	.551
Endurance running[a]	–0.03 (0.96)	–0.02 (0.97)	–0.03 (0.95)	.041
BMI[a]	–0.02 (0.97)	–0.01 (0.98)	–0.02 (0.97)	.287
PFI[a]	0.63 (2.92)	0.62 (2.85)	0.64 (2.98)	.115

Abbreviations: BMI, body mass index; MVPA, moderate to vigorous physical activity; PA, physical activity; PE, physical education; PFI, physical fitness indicator.
[a]Mean (SD) and *t* tests were performed for continuous variables.

in the auto-clustering model are shown in Supplementary Tables S8 and S9 (available online), respectively. For individual factors, cluster 1 was labeled "highest physical activity" characterized by highest moderate to vigorous PA time as 0.68 (0.64) hours per day, cluster 2 was labeled "longest sedentary time and skipping breakfast" characterized by longest sedentary time as 8.38 (5.12) hours per day and highest proportion of having breakfast <7 days per week (98.3%), and cluster 3 was labeled "physical inactivity and insufficient protein consumption" characterized by lowest moderate to vigorous PA time as 0.57 (0.54) hours per day and highest proportions of eating egg (100.0%) and drinking milk (100.0%) <7 days per week. The cluster process had good quality (silhouette coefficient = 0.5) and substantial agreement (κ coefficient = .71). Similarly, clusters in family level were labeled "non-single children and low parental education level," "single children and high parental education level," and "no PA support and no PA preference," with fair quality (silhouette coefficient = 0.4) and almost perfect agreement (κ coefficient = 1.00). Clusters in school level were labeled "ideal environment," "PE occupied," "no interclass exercise," "insufficient PE frequency," and "no sports meeting," with good quality (silhouette coefficient = 0.8) and almost perfect agreement (κ coefficient = 1.00).

Figure 2 showed the distributed characteristics of clusters. Sex differences and urban–rural differences in each level were all significant among these clusters ($P < .05$). Importantly, we observed that with age, the proportions of participants in "highest physical activity" cluster and "ideal environment" cluster were gradually decreasing, whereas the proportions of participants in "no PA support and no PA preference" cluster were gradually increasing (*P-trend* < .05). Most importantly, we discovered similar trends of the proportions of these clusters with PFI level (*P-trend* < .05).

Association Between Health-Related Physical Fitness and Clustered Subgroups

Associations between clusters and PFI were shown in Supplementary Table S6 (available online) and Figure 3. For individual level, "longest sedentary time and skipping breakfast" cluster (odds ratio [OR] = 1.18; 95% confidence interval [CI], 1.12–1.24) and "physical inactivity and insufficient protein consumption" cluster (OR = 1.07; 95% CI, 1.02–1.12) were more likely to have a higher proportion of low PFI. In terms of family level, the proportions of sample with low PFI in the "single children and high parental education level" cluster (OR = 1.15; 95% CI, 1.10–1.21) and "no PA support and no PA preference" cluster (OR = 1.30; 95% CI, 1.25–1.36) were higher. In the case of school level, "PE occupied" cluster (OR = 1.06; 95% CI, 1.01–1.11) and "insufficient PE frequency" cluster (OR = 1.16; 95% CI, 1.08–1.24) were demonstrated to have higher proportions of low PFI.

Furthermore, sex and age were proved to have significant interaction effects on the factors of PFI (*P-interaction* < .05), bringing out the stratified analysis shown in Supplementary Table S7 (available online) and Figure 4. Boys were more frangible in family-level "single children and high parental education level" cluster and "no PA support and no PA preference" cluster, while girls were more vulnerable in individual-level "longest sedentary time and skipping breakfast" cluster and school-level "PE occupied" cluster and "insufficient PE frequency" cluster (*P-interaction* < .05). Children and adolescents aged 9–15 years were more sensitive in school-level "insufficient PE frequency" cluster, while sample age 16–18 years was more susceptible in family-level "single children and high parental education level" cluster (*P-interaction* < .05).

Discussion

To date, this is the first study using a national, large-sample survey to automatically cluster individual-, family-, and school-level factors to analyze their characteristics and associations with PFI among children and adolescents, with subgroup differences explored completely, enriching information on factors influencing health-related physical fitness in a novel way. Overall, we confirmed different clusters existed in individual, family, and school levels, respectively, among which the proportions of relatively healthy clusters gradually decreased with age. Moreover, individual-, family-, and school-level clusters were all related to PFI, with individual and family clusters playing a more important role. Further, sex and age differences were borne out significantly, that is, girls were more vulnerable to individual- and school-level factors, while boys were more susceptible to family factors; the younger students were more sensitive to school factors, and the older students were more susceptible to family factors.

As a core aspect closely related to health, the analysis of individual behaviors has been the focus of numerous studies[18] and the key targets for improvements worldwide as well.[24] Consistent with previous evidence,[10,11] we found obvious clustering effects of physical inactivity and sedentary behaviors with unhealthy diets, validating the lifestyle behaviors among children and adolescents were complex and multifaceted, rather than simply affecting health independently. As for health-related physical fitness, we observed that 2 relatively unhealthy clusters were indeed associated with lower PFI, specifically the group characterized as "longest sedentary time and skipping breakfast," alerted as the more vulnerable population with urgent need to reduce sedentary behaviors, have breakfast regularly, and increase PA. In accordance with other findings,[10] girls classified in "longest sedentary time and skipping breakfast" cluster were more susceptible to low PFI, and by virtue of the fact that, different from boys who are more likely to enroll in high-intensity sports, girls would like to spend more time on

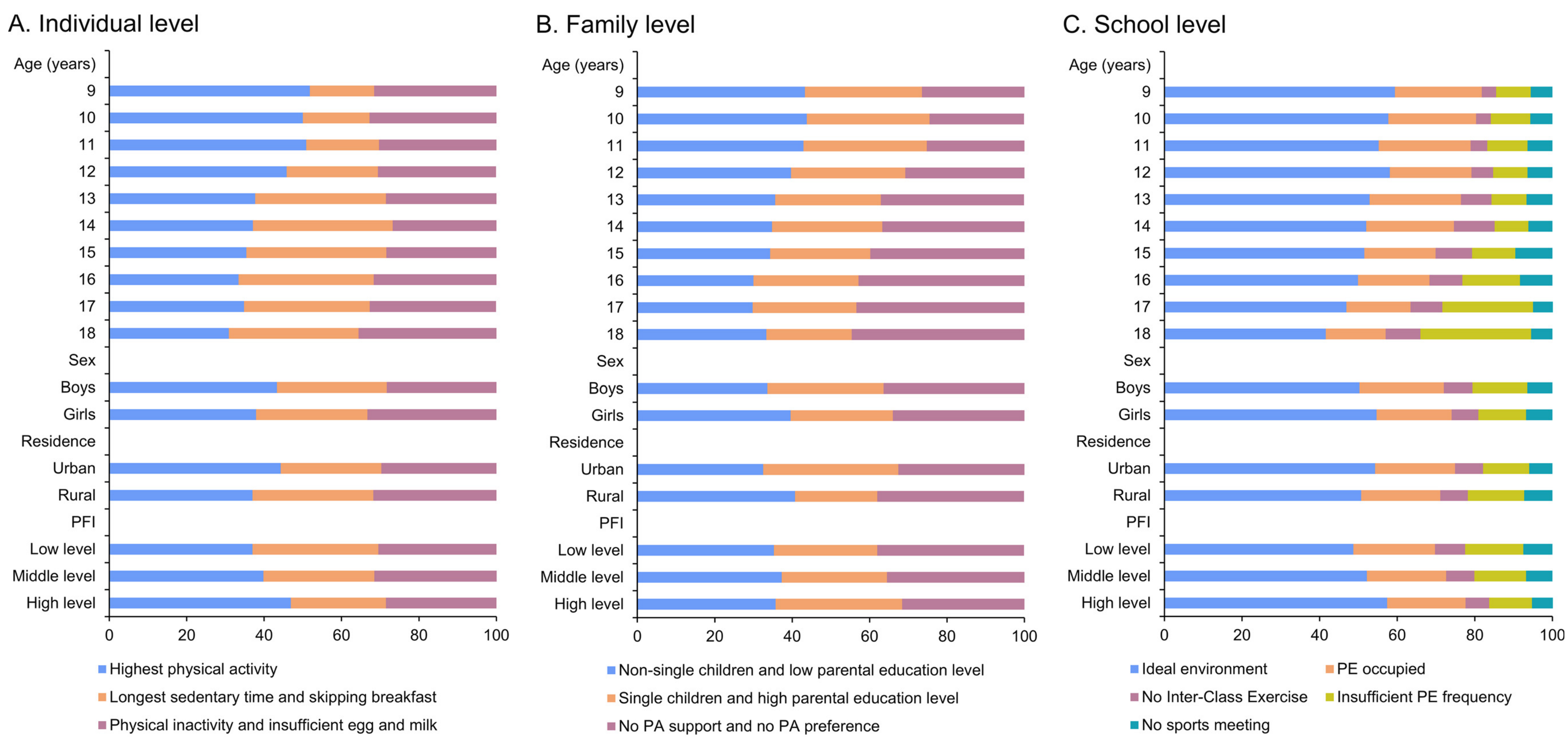

Figure 2 — Distributed characteristics of individual, family, and school cluster groups. *Linear-by-linear tests were performed for the trend analysis of age and PFI, taking the "highest physical activity," "no PA support and no PA preference," and "ideal environment" as target group for tests, respectively. #Chi-square tests were performed between sex and residence among these clusters. PA indicates physical activity; PE, physical education; PFI, physical fitness indicator.

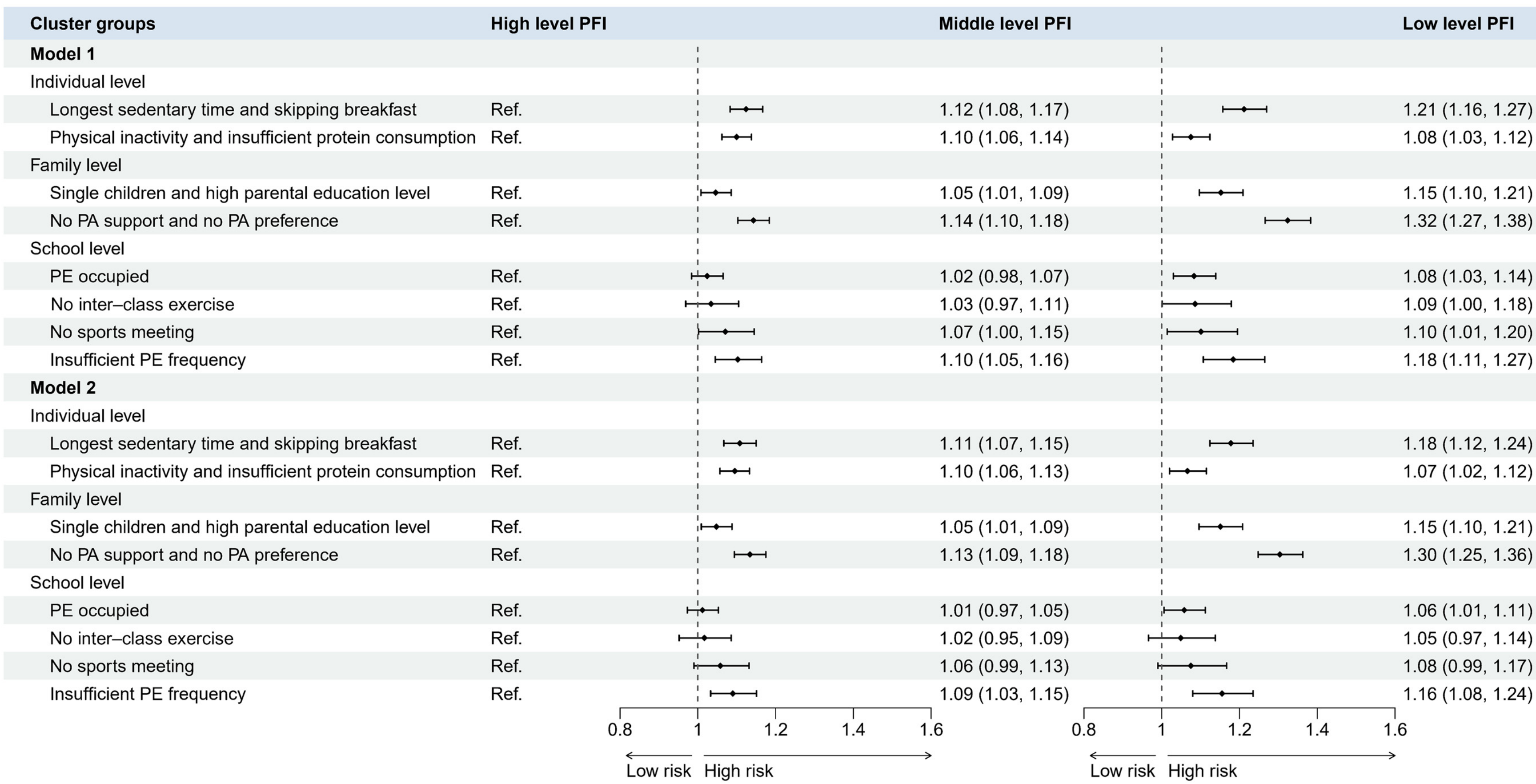

Figure 3 — Association between PFI and cluster groups. Model 1 was adjusted for school, age, sex, and residence. Model 2 was adjusted for school, age, sex, residence, and individual-, family-, and school-level cluster groups. PA indicates physical activity; PE, physical education; PFI, physical fitness indicator.

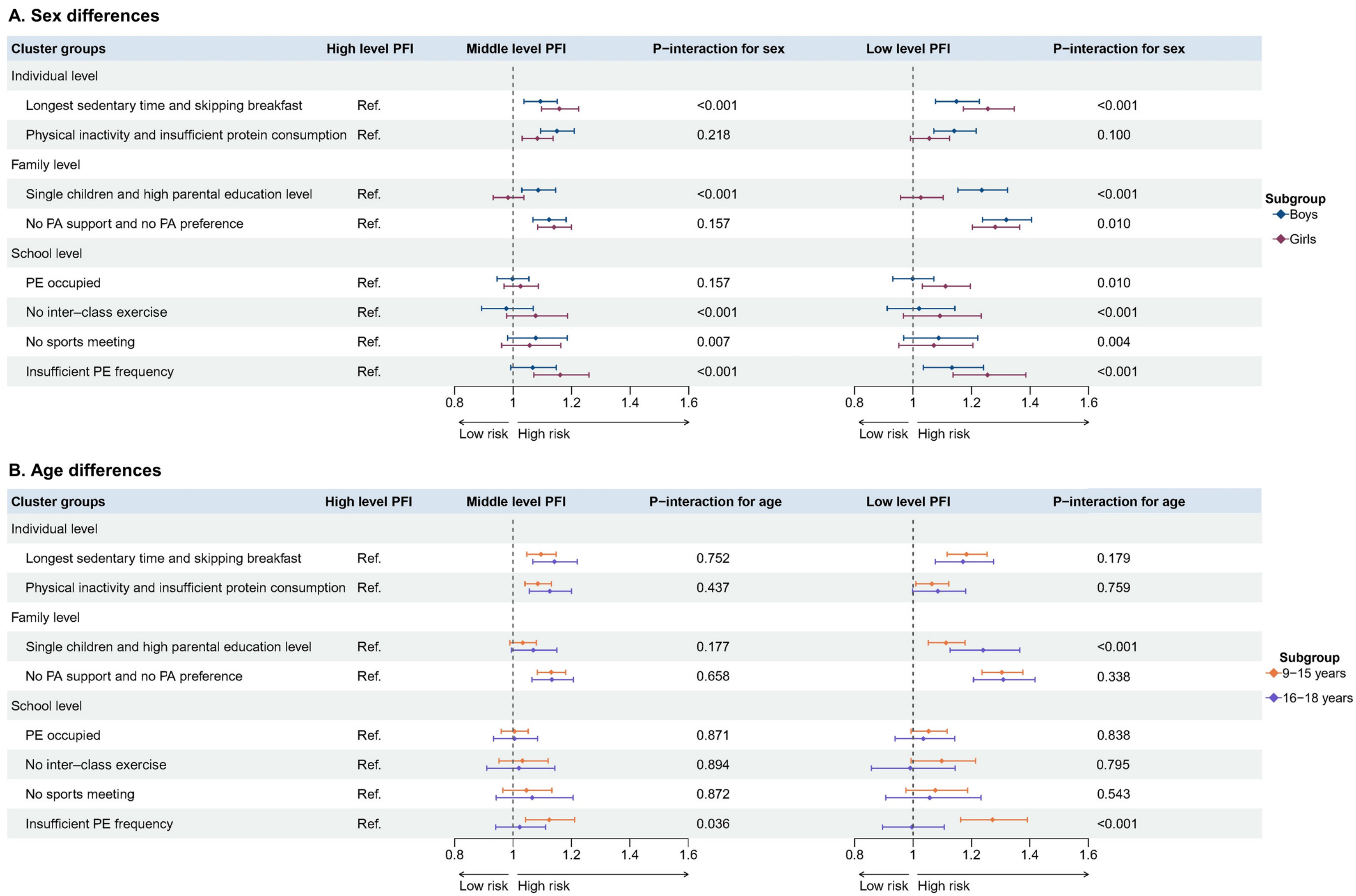

Figure 4 — Association between PFI and cluster groups by sex and age; adjusted for school, age, sex, residence, and individual-, family-, and school-level cluster groups. PA indicates physical activity; PE, physical education; PFI, physical fitness indicator.

medium- to low-intensity exercises, resulting in sedentary behaviors, such as prolonged TV and computer watching, and may lead to a higher risk.[25,26] It is worth noting that insufficient PA, increasing sedentary behaviors, and high-calorie diets have been found to have grave outcomes risking related interventions harder to achieve goals, requiring feasible and effective measures from new perspectives.[27,28] Based on the above status quo, this study demonstrated that identifying clustering groups with regard to individual behaviors, taking sex differences into account, and carrying out corresponding interventions targeting specific insufficient factors can possibly accelerate the pace of promoting health-related physical fitness among children and adolescents.

Primary caregivers, upbringing environments and parents, as well as family, typically play a major role in children's growth and development and in shaping their PA behaviors.[29] This study described single children who typically came from a family with high parental education levels, which was mainly attributed to implementation of the one-child policy in China over the past few decades, resulting in a high proportion of senior intellectuals having only one child.[30] Notably, as shown in previous evidence, children and adolescents from these families were often at higher risk for health problems, including health-related physical fitness which might be related to single children having gained more resources than those with siblings, but the current nutritional and social environment possibly encouraged the adoption of unhealthy lifestyles in turn.[31] In addition, boys were more likely in cases for family to have better resource allocation and more coddling, [32] and adolescents of higher age had higher family expectations and higher education pressure.[33] Of greater significance, while the existing family structure failed to be changed in time, parental support and preference for PA were more dominant for health-related physical fitness, which has been also testified by this study. Numerous intervention studies have demonstrated that parental supervision, support, and co-participation for PA might promote the PA levels to varying degrees; thereby, promoting health among their children.[34,35] All in all, we encourage a birth-friendly social environment and PA-friendly family environment to improve health-related physical fitness among children and adolescents, especially for boys and higher age groups.

Unlike individual- and family-level factors, the clustering circumstance among school-level factors in our study was not obvious. It is worth noting that the school environment could affect the health-related physical fitness as well among children and adolescents, especially the factors related to PE, which was consistent with the comprehension of the international community.[16,36] The World Health Organization also emphasized the significance in improving school PA environment, and of strengthening the construction of PE when calling for recommendations to health-promoting schools.[36] We too observed girls and younger age groups were more sensitive to school PA environment when it came to health-related physical fitness problems, which might be attributable to being less active in PA outside of PE among girls,[37] and simpler forms and contents of PA; thus, needing more classes among lower age groups,[38] respectively. Further, regarded as the main place for learning and exercise among children and adolescents, the significance of school on health-related physical fitness is not completely reflected in the direct effect but is in being a central place that is easy to control and manage while making interventions on individual behaviors and family environment.[39,40] In other words, we should not only pay attention to the direct role of school PA environment in the health-related physical fitness among children and adolescents but also place great emphasis on the indirect role of school in improving students' individual behaviors and family environment, which were recognized as important factors for health-related physical fitness as well.

Therefore, our findings support the opinion to consider individual, family, and school engagement while setting policies for health promotion and enhancing health-related physical fitness among children and adolescents. However, as shown in our results, individual behaviors, family, and school environment were not ideal now, and the proportion of healthy groups decreased with lower with age, implying that although academic pressure and life pressure are increasing, it is necessary to create a good environment for children and adolescents, for the sake of their physical and mental health. Correspondingly, China and countries around the world have successively issued guidelines and action plans aimed at improving PA and health-related physical fitness among children and adolescents, advocating to offset the negative factors by integrated interventions and from multiple perspectives.[27,36] It is noteworthy that health lifestyle factors at the individual level are generally treated as the core of health-related physical fitness improvement among children and adolescents, while supportive environment at the family and school could greatly contribute to improving health through the individual level.[16] Our research implicates that, based on the existing policies and interventions, considering the cluster characteristics at different levels in different regions, and identifying serious factors and vulnerable groups, thereby taking targeted interventions may simplify the complex steps and improve the effect. For instance, "longest sedentary time and skipping breakfast" cluster at individual level, "no PA support and no PA preference" cluster at family level, and "insufficient PE frequency" cluster at school level should be paid greater attention in Chinese children and adolescents owing to the highest risk observed to be with low physical fitness, respectively, putting forward the urgent need to improve the corresponding adverse clustered factors. Moreover, the most significant value of our findings was that we confirmed the clustering of factors influencing physical fitness in children and adolescents, with sex and age differences, but the specific characteristics of clusters might be likely to vary across countries and populations. Additional evidence is needed to be generated by successive studies in each country.

However, there were several unavoidable limitations in our study. First, it is generally recognized that a cross-sectional study could only provide associations between factors; therefore, longitudinal studies are necessary to verify causality. Second, although the big sample in this study comprised the broad age span of 9–18 years, it did not cover children under 9 years; therefore, the conclusions of this study should be extrapolated to younger age groups with caution. Third, we constructed a PFI using 6 components including BMI, forced vital capacity, standing long jump, sit-and-reach flexibility, body muscle strength, and endurance running, which has not yet been internationally verified, but previous studies have proven the calculated PFI could well capture the physical fitness among children and adolescents comprehensively.[3] In addition, most of the selected factors in our study were categorical variables, which might tend to model poorly, meaning future research could collect continuous variables as possible to verify and improve our results. Last, although this study has comprehensively considered more than a dozen influencing factors, there are still some factors that have not been obtained, such as community environment and early life experience.

In conclusion, this study identified distinct clustering characteristics at the individual, family, and school levels, with the above 3 levels of clusters all confirmed to be directly related to the health-related physical fitness among children and adolescents, where individual- and family-level clusters presented more apparent effects. Furthermore, boys were more vulnerable to family-level clusters, while girls were more sensitive to individual- and school-level clusters, and younger children were more susceptible to school-level clusters, while older age groups were more susceptible to family-level clusters. Consequently, the main findings provided new perspective and evidence for developing more targeted interventions and policies based on various identified clusters and vulnerable subgroups to achieve more effective harvests.

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