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Preplanned Studies

Effect of Telehealth Follow-up Consultation in Pediatric Acute Otitis Media — Shenzhen City, Guangdong Province, China, 2023–2024

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Summary

What is already known about this topic?

Between 50% and 85% of children experience at least one episode of acute otitis media (AOM) by age three. Since the coronavirus disease 2019 (COVID-19) pandemic, numerous hospitals across China have integrated telehealth solutions into their pediatric care services.

What is added by this report?

Our study found patients with ear pain relief was 84% in the telehealth follow-up group compared to 81% in the in-person follow-up group, showing no statistically significant difference (*P*=0.57). Hearing loss was documented in 21 cases from the telehealth group and 23 cases from the in-person follow-up group (*P*=0.73). Patient satisfaction scores were comparable between groups, with mean scores of 4.47 for telehealth and 4.49 for in-person follow-up (*P*=0.87). Multivariate regression revealed no significant difference in patient satisfaction between telehealth and in-person follow-up (*P*=0.21).

What are the implications for public health practice?

Telehealth services can effectively bridge geographical healthcare disparities while optimizing pediatric care delivery systems

ABSTRACT

Introduction: Between 50% and 85% of children experience at least one episode of acute otitis media (AOM) by age three. Since the coronavirus disease 2019 (COVID-19) pandemic, numerous hospitals across China have integrated telehealth solutions into their pediatric care services. Our research team introduced the Telehealth and Autonomous Mobile Clinic Framework, which was published in the Bulletin of the World Health Organization in September 2022.

Methods: The investigation employed a retrospective cohort design. The study population comprised 200 pediatric patients diagnosed with AOM who received either telehealth follow-up consultation or traditional in-person clinic visits. Bivariate analyses examined relationships between telehealth follow-up consultation and patient outcome in ear pain, hearing loss, and patient satisfaction between telehealth and in-person AOM follow-up groups. Multivariate regression analysis evaluated associations between ear pain (a primary clinical outcome) and telehealth utilization, hearing loss, and patient satisfaction, with adjustments for age and gender.

Results: Ear pain relief was reported by 84% of patients in the telehealth follow-up group compared to 81% in the in-person follow-up group, showing no statistically significant difference (*P*=0.57). Hearing loss was documented in 21 cases from the telehealth group and 23 cases from the in-person follow-up group (*P*=0.73). Patient satisfaction scores were comparable between groups, with mean scores of 4.47 (range: 2.47–4.92) for telehealth and 4.49 (range: 2.72–4.94) for in-person follow-up (*P*=0.87). Multivariate regression revealed no significant difference in patient satisfaction between telehealth and in-person follow-up (*P*=0.21).

Conclusion: This retrospective study provides compelling evidence for the effectiveness and feasibility of telehealth follow-up consultations in pediatric otitis media management. Our findings demonstrate that telehealth consultations achieve comparable outcomes to in-person follow-up visits for AOM patients.

Acute otitis media (AOM) is the most frequently diagnosed pediatric acute care condition, with 50% to 85% of children experiencing at least one episode of AOM by the age of three (AAFP). Clinical manifestations include otalgia (indicated by ear rubbing, tugging, or holding), fever, irritability, otorrhea, anorexia, and, in some cases, vomiting or lethargy (*1*–*2*). The diagnosis of AOM in children is established by the symptomatic presentation of moderate to severe tympanic membrane bulging, new-onset otorrhea not attributable to acute otitis externa, mild tympanic membrane bulging accompanied by recent-onset ear pain (within 48 hours), or intense tympanic membrane erythema (*3*). Management include pain control combined with either watchful waiting or antibiotic therapy. The strategy selection is determined by the patient's age, severity of symptoms, and whether the condition is unilateral or bilateral (*4*).

Telehealth has transformed pediatric care delivery (*5*). A technical report from the American Academy of Pediatrics indicates that telehealth can enhance patient access to pediatric expertise while facilitating improved clinician communication, ultimately leading to more efficient, higher-quality, and cost-effective care (*6*). Evidences support the efficacy of telehealth in pediatric consultations. Research by Davis from the University of California demonstrated high satisfaction rates among both patients and providers during pediatric telehealth consultations (*7*). Additionally, a study by the University of Rochester Medical Center revealed correlations between telehealth consultations for pediatric asthma patients and enhanced symptomatic management and decreased hospitalization rates (*8*). These findings support telehealth as an effective tool for enhancing pediatric healthcare delivery.

This retrospective cohort study evaluated pediatric AOM patients who received either telehealth follow-up consultation or traditional in-person clinic visits between September 1, 2023, and March 31, 2024, at the Shenzhen United Family Hospital. The study population comprised 200 patients equally distributed between the telehealth (n=100) and in-person (n=100) groups over a 2-week period. All telehealth consultations were conducted through the United Family Hospital teleconsultation application. Primary outcomes included patient satisfaction, ear pain, hearing loss, and the Ear-Nose-Throat (ENT) specialists' recording and evaluation of symptoms during the telehealth consultations.

Patient satisfaction scores showed no significant statistical differences between the telehealth (mean 4.47, range: 2.47–4.92) and in-person follow-up groups (mean 4.49, range: 2.72–4.94; P=0.87). Multivariate regression analysis, adjusting for age, gender, ear pain, and hearing loss, further confirmed no significant differences in patient satisfaction between the two groups (P=0.21). This study demonstrates that telehealth consultations achieve comparable outcomes to in-person visits in terms of patient satisfaction and clinical outcomes of AOM patients. Further research examining the cost-effectiveness and health policy implications is necessary to enhance the accessibility and efficacy of pediatric telemedicine services.

The investigation employed a retrospective cohort design. The study population comprised pediatric patients diagnosed with AOM who received either telehealth follow-up consultation or traditional in-person clinic visits between September 1, 2023, and March 31, 2024, at Shenzhen United Family Hospital. Patient records were identified through electronic health records (EHRs) based on the following criteria: age below 18 years at diagnosis, confirmed AOM diagnosis, receipt of telehealth follow-up consultation, and documented treatment for AOM. Exclusion criteria encompassed a history of chronic otitis media, tympanic membrane perforation, or other ear-related conditions.

The study population consisted of 200 children with confirmed AOM diagnoses, equally allocated between telehealth consultation (n=100) and in-person clinic follow-up (n=100) groups for a 2-week period. Data extraction was performed from the hospital's outpatient routine database within the EHR system. Patient assignment to either telehealth or in-person follow-up groups was randomized using a computerized numerical generator process, with odd numbers designated for telehealth and even numbers for in-person follow-up. Hospital nurses with appropriate record access privileges conducted data retrieval while remaining blinded to the study design and anticipated outcomes.

The data collection encompassed routine demographic information from EHRs, including patient characteristics, treatment details, and relevant outcomes. All data were extracted from existing routine documentation rather than being specifically collected for this study. Patient outcomes were evaluated based on symptom resolution, recurrence, and AOM persistence following treatment completion. The assessment of telemedicine services' feasibility and accessibility incorporated both patient and provider satisfaction metrics.

All telehealth consultations were conducted using the United Family Hospital teleconsultation mobile application platform, accessible to both healthcare providers and patients. Following AAFP guidelines, ear pain and hearing loss were identified as primary clinical indicators for AOM evaluation, with patient satisfaction serving as the key patient-reported outcome (PRO). As AOM typically shows symptomatic improvement within 2 weeks of appropriate treatment, follow-up assessments were scheduled at this interval (*9*). During ear, nose, and throat (ENT) specialist-led telehealth consultations, ear pain and hearing loss were systematically evaluated based on patient reports. Patient satisfaction scores were similarly assessed during these consultations. Given the pediatric population, parents facilitated all interactions during both telehealth and in-person follow-up visits.

Patient selection utilized a systematic random sampling approach from hospital outpatient department records to ensure an equal probability of inclusion and minimize selection bias. Patient recruitment occurred continuously throughout the specified study period to maintain the target sample size and account for potential attrition or exclusions based on eligibility criteria. To prevent selection bias, researchers conducting follow-up assessments were blinded to the recruitment process. Patient demographics, baseline characteristics, follow-up information, and patient-reported outcomes were summarized using descriptive statistics.

Bivariate analyses examined relationships between telehealth follow-up consultation and patient outcomes, specifically employing two-sample t-tests to compare mean differences in ear pain, hearing loss, and patient satisfaction between telehealth and in-person AOM follow-up groups. Multivariate regression analysis evaluated associations between ear pain (a primary clinical outcome) and telehealth utilization, hearing loss, and patient satisfaction, with adjustments for age and gender.

The sample size was determined using the web-based Sample Size Estimation software developed by John Eng and Russell H. Morgan at Johns Hopkins University School of Medicine (*10*). To detect a minimum difference of 1 unit in patient satisfaction scores, with 80% statistical power and a two-tailed significance level of 0.05, a minimum of 71 subjects was required. Our sample size of 200 achieved 93% power. STATA (version 16 for Windows, By StataCorp LLC. 2024, Texas, United States) was used to conduct all analyses.

Our evaluation focused on three primary indicators for AOM, which were patient satisfaction, ear pain, and hearing performance. Patient satisfaction assessed the quality of telehealth consultation services, while ear pain and hearing performance measured clinical outcomes. As shown in Table 1, the demographic characteristics were comparable between groups. The mean age was 5.66 years in the telehealth group and 5.53 years in the in-person visit group. The gender distribution was balanced, with male patients comprising 51% (51/100) of the telehealth group and 53% (53/100) of the in-person group.

After 2 weeks of treatment, ear pain relief was reported by 84% of patients in the telehealth follow-up group compared to 81% in the in-person follow-up group, showing no statistically significant difference (*P*=0.57). Hearing loss was documented in 21 cases from the telehealth group and 23 cases from the in-person follow-up group (*P*=0.73). Patient satisfaction scores were comparable between groups, with mean scores of 4.47 (range: 2.47–4.92) for telehealth and 4.49 (range: 2.72–4.94) for in-person follow-up (*P*=0.87).

Multivariate regression analysis, presented in Table 2, examined the relationship between consultation method and patient satisfaction while adjusting for covariates including ear pain, hearing loss,

TABLE 1. Comparison of telehealth and in-person AOM follow-up outcomes.

Variables	Telehealth (*N*=100)	In-person (*N*=100)	t value	*P*
Age (years)	5.66 (3.25–9.12)	5.53 (3.01–8.89)		
Gender				
Male	51	53		
Female	49	47		
Ear painful relief	84	81	1.97	0.57
Hearing loss	21	23	0.73	0.73
Patient satisfaction	4.47 (2.47–4.92)	4.49 (2.72–4.94)	0.87	0.87

Note: Data shown in table sessions Telehealth and In-person are subject numbers (*n*), with the mean and (SD) of subjects, respectively. The t value and *P* are using two-tail t and *P* performance.
Abbreviation: AOM=acute otitis media; SD=standard deviation.

TABLE 2. Multivariate regression on AOM patient satisfaction 2 weeks follow-up.

Variables	Coefficients	Standard Error	t Stat (two tail)	*P* (two tail)	Lower 95% *CI*	Upper 95% *CI*
Telehealth	−0.07	0.062	−1.23	0.21	−0.201	0.045
Ear pain	−1.66	0.154	−10.77	<0.01	−1.973	−1.362
Hearing loss	−0.38	0.126	−3.04	<0.01	−0.637	−0.136
Age	0.01	0.018	1.56	0.55	−0.026	0.048
Gender	0.09	0.062	0.76	0.12	−0.025	0.221

Note: The multivariate regression analysis in this study is adjusted R square of Model (R^2) = 0.76. Patient satisfaction using PSQ-18 scoring, ranging from 1–5. All results have already been adjusted for each covariate, e.g. Telehealth results have been adjusted for ear pain, hearing loss, age, and gender. Other results were yielded after adjusting related covariates and confounders.
Abbreviation: AOM=acute otitis media; *CI*=Confidence Interval.

age, and gender. The analysis revealed no significant difference in patient satisfaction between telehealth and in-person follow-up (*P*=0.21). However, patient satisfaction scores were negatively associated with both ear pain (t=−1.23, *P*<0.01) and hearing loss (t=−3.04, *P*<0.01). Neither age nor gender showed statistically significant associations with patient satisfaction (*P*>0.05). Given the demonstrated equivalence between telehealth and in-person follow-up for AOM patients, healthcare providers' expansion of teleconsultation services to other suitable conditions should be considered to reduce wait times and improve healthcare delivery efficiency.

DISCUSSION

This retrospective study provides compelling evidence for the effectiveness and feasibility of telehealth follow-up consultations in pediatric otitis media management. Our findings demonstrate that telehealth consultations achieve comparable outcomes to in-person follow-up visits for AOM patients. Furthermore, telehealth shows significant potential to revolutionize pediatric care delivery by expanding access across geographic boundaries, optimizing pediatric workforce utilization, and addressing disparities in healthcare accessibility.

While our study offers valuable insights, several limitations warrant consideration. First, our analysis focused primarily on patient satisfaction and select clinical outcomes, leaving the cost-effectiveness of teleconsultation unexplored. Additionally, as a retrospective cohort study, the evidence level does not match that of a randomized controlled trial. Moreover, the implementation of telehealth technology requires more than just clinical outcome validation. The development of evidence-based best practices and comprehensive policies specific to pediatric telemedicine is essential for widespread adoption.

A critical consideration is the establishment of appropriate reimbursement mechanisms for remote services across various payment models, including fee-for-service, capitation, and value-based plans. Rigorous research and metric development are fundamental to creating evidence-based best practices and policies for these emerging care delivery models.

Our findings demonstrate that telehealth consultations achieve equivalent outcomes to in-person follow-up visits for AOM patients in terms of satisfaction and clinical outcomes. However, additional research examining cost-effectiveness and health policy implications is necessary to optimize the accessibility and efficacy of pediatric telemedicine. As pediatric healthcare transitions from traditional fee-for-service models to alternative payment methods, telehealth presents unique opportunities to establish sustainable, value-based population health models. This study was conducted under a retrospective design utilizing routine outpatient datasets from existing patient databases. The hospital's Institutional Review Board approved the study protocol and ensured data privacy compliance.

Conflicts of interest: No conflicts of interest.

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Methods and Applications

Reference Values of Non-Cycloplegic Spherical Equivalent for Screening and Predicting Myopia Among Children and Adolescents — China, 2020-2024

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ABSTRACT

Introduction: Non-cycloplegic refraction is widely utilized in vision screening. However, interpreting non-cycloplegic refraction results remains a significant challenge in both clinical practice and public health settings. This study aimed to establish grade- and sex-specific reference values for non-cycloplegic spherical equivalent (SE) to enhance myopia screening and risk prediction among Chinese students.

Methods: A comprehensive study was conducted between 2020 and 2024, involving 67,260 students from kindergarten through high school across 10 provincial-level administrative divisions (PLADs) in China. The Lambda-Mu-Sigma method was employed to model non-cycloplegic SE. Reference values were established by calculating SE centiles corresponding to myopia and high myopia prevalence across grades 0 through 12.

Results: Among boys, the estimated prevalence of myopia and high myopia increased from 1.2% and <0.1% in grade 0 (senior kindergarten) to 82.4% and 11.6% in grade 12 (third year of high school), respectively. For twelfth-grade boys, the 82.4th and 11.6th percentiles of SE (–0.99 D and –6.16 D) were established as reference values for screening myopia and high myopia, respectively. The corresponding percentiles in lower grades served as predictive reference values for grade 12 outcomes. For instance, a grade-0 boy with non-cycloplegic SE>0.70 D (82.4th percentile) was predicted to remain free of myopia before grade 12. Similarly, SE>–0.73 D (11.6th percentile) indicated a low likelihood of developing high myopia before grade 12.

Conclusions: This study established comprehensive non-cycloplegic SE reference values for screening and predicting myopia among Chinese students. The methodology developed here may be applicable to other regions where student myopia prevalence patterns demonstrate relative stability.

Myopia represents a significant public health challenge. In China, myopia affected over 80% of high school students in 2018, with approximately one-fifth of myopic students developing high myopia (*1*). Early prediction of myopia risk, identification of susceptible individuals, and timely intervention are essential strategies to delay myopia onset and minimize the risk of high myopia progression (*2*). While cycloplegic spherical equivalent (SE) remains the gold standard for myopia diagnosis and provides more reliable predictive indicators, non-cycloplegic SE is predominantly used in public health screening programs due to cycloplegia's procedural complexity and potential adverse effects (*3*–*4*).

METHODS

The National Disease Control and Prevention Administration of China coordinated a nationwide hyperopia reserve survey across 10 provincial-level administrative divisions (PLADs) between 2020 and 2024: Beijing, Shanxi, Liaoning, Zhejiang, Shandong, Henan, Hunan, Guangdong, Chongqing, and Shaanxi. In most PLADs, two cities were selected based on economic development levels: one more developed and one less developed. Exceptions included Liaoning Province, where six cities were selected (three more developed, three less developed) based on per capita gross domestic product; Beijing and Chongqing, where two districts were selected (one more developed, one less developed); and Shandong Province, where two districts from a single city were selected (one more developed, one less developed). Students from senior kindergarten through high school were selected using a multistage cluster sampling design at each site. This study utilized the survey data to establish sex- and grade-specific reference values of non-cycloplegic SE from senior kindergarten (grade 0) through third-year high school (grade 12).

Refraction measurements were conducted using identical desktop autorefractors for both non-cycloplegic and cycloplegic (0.5% tropicamide, administered 4 times at 5-minute intervals) conditions. Certified professionals performed all eye examinations to ensure measurement accuracy. Quality control measures included random retesting of 5% of participants at each survey site, with additional testing required if measurements differed by more than 0.5 D. Due to the high correlation between ocular parameters of both eyes, only right eye data are presented. SE was calculated by adding spherical power (D) to half the cylindrical power (D). Myopia was defined as cycloplegic SE≤−0.50 D, and high myopia as ≤ −6.00 D.

Statistical analyses were conducted using R software (version 4.2.2, R Foundation for Statistical Computing, Vienna, Austria). The non-cycloplegic SE data were modeled using the Lambda-Mu-Sigma (LMS) method, which assumes that non-cycloplegic SE values at each grade follow a normal distribution after Box-Cox power transformation. The 100 α percentile of non-cycloplegic SE at grade t ($C_{100\propto}(t)$) was calculated using the following equation. In this equation, M(t) represents the median non-cycloplegic SE at grade t, S(t) denotes the coefficient of variation, and L(t) indicates the power of normal transformation. These three parameters were modeled as smooth functions of grade using P-splines implemented through the GAMLSS package in R. Z_α represents the z-score corresponding to the 100 α percentile of the standard normal distribution.

$$\begin{cases} C_{100\propto}(t) = M(t)\left(1 + L(t) \times S(t) \times Z_{\propto}\right)^{-L(t)}, L(t) \neq 0 \\ C_{100\propto}(t) = M(t)\exp\left(S(t) \times Z_{\propto}\right), L(t) = 0 \end{cases}$$

For each grade, we calculated the corresponding percentiles of non-cycloplegic SE based on the smoothed prevalence of myopia from grades 0 to 12 (Supplementary Table S1, available at https://weekly.chinacdc.cn/), which formed the basis for determining grade-specific reference values for screening and predicting myopia. For instance, given that the myopia prevalence among grade 12 boys was 82.4%, we selected the 82.4th percentile of non-cycloplegic SE as the reference value for screening myopia in grade 12 boys. Similarly, the 82.4 percentile of non-cycloplegic SE for boys in lower grades served as a reference value for predicting myopia development by grade 12. The same methodological approach was applied to establish reference values for screening and predicting high myopia.

RESULTS

A total of 62,482 students were included in the analysis. The sample comprised 30,188 (48.3%) boys and 28,957 (46.3%) students from economically more developed areas. The distribution across educational levels was: 14,290 (22.9%) kindergarten students, 41,385 (66.2%) primary school students, 3,985 (6.4%) middle school students, and 2,822 (4.5%) high school students. The flow diagram of the study population is presented in Supplementary Figure S1 (available at https://weekly.chinacdc.cn/).

Table 1 and Table 2 present the grade-specific reference values of non-cycloplegic SE for screening myopia in boys and girls, respectively, along their main diagonals. These reference values demonstrated a high screening accuracy of 91.4%, with 82.4% sensitivity and 94.6% specificity. Above the main diagonal, the tables show reference values at lower grades that predict myopia development at corresponding higher grades. A student whose non-cycloplegic SE exceeds the reference value is predicted to remain free of myopia until that grade. Below the main diagonal, the tables display predicted non-cycloplegic SE values through grade 12, assuming myopia onset at specific grades. Notably, girls' reference values above the main diagonal generally exceeded those of boys, while values below the main diagonal were typically lower for girls compared to boys.

Table 3 and Table 4 present the reference values for screening and predicting high myopia for boys and girls, respectively, from grades 4 through 12. Reference values for grades 0 through 3 were omitted due to insufficient high myopia prevalence (less than 0.1%) to establish reliable reference values. The reference values for high myopia showed minimal gender differences across all grades.

DISCUSSION

This study established sex- and grade-specific reference values for non-cycloplegic SE to screen and predict myopia and high myopia among Chinese students from senior kindergarten through the third grade of high school. We chose to organize reference values by grade rather than age because eye health screening programs are typically implemented at the school level, and research has shown that grade level

TABLE 1. Grade-specific reference values of non-cycloplegic SE for screening and predicting myopia in boys.

Grade	Percentiles of non-cycloplegic SE (D)												
	1.2	**5.8**	**15.7**	**29.5**	**42.5**	**52.9**	**62.2**	**70.3**	**76.2**	**79.5**	**81.2**	**82.1**	**82.4**
0	**−1.71**	−1.05	−0.58	−0.23	0.01	0.18	0.33	0.47	0.57	0.64	0.67	0.69	0.70
1	−1.91	**−1.21**	−0.72	−0.36	−0.11	0.07	0.23	0.37	0.48	0.54	0.58	0.60	0.61
2	−2.49	−1.64	**−1.06**	−0.64	−0.35	−0.14	0.04	0.20	0.32	0.40	0.44	0.46	0.47
3	−3.58	−2.37	−1.59	**−1.04**	−0.67	−0.41	−0.19	0.01	0.16	0.26	0.31	0.34	0.34
4	−4.88	−3.21	−2.19	−1.49	**−1.03**	−0.70	−0.42	−0.18	0.01	0.13	0.19	0.23	0.24
5	−6.05	−4.02	−2.79	−1.95	−1.39	**−1.00**	−0.68	−0.38	−0.16	−0.02	0.06	0.10	0.11
6	−7.07	−4.82	−3.42	−2.45	−1.81	−1.36	**−0.98**	−0.64	−0.38	−0.22	−0.13	−0.08	−0.07
7	−7.89	−5.53	−4.02	−2.96	−2.26	−1.76	−1.33	**−0.95**	−0.65	−0.47	−0.37	−0.32	−0.30
8	−8.43	−6.08	−4.53	−3.41	−2.66	−2.12	−1.66	−1.25	**−0.92**	−0.73	−0.62	−0.56	−0.54
9	−8.77	−6.47	−4.90	−3.76	−2.97	−2.41	−1.92	−1.47	−1.13	**−0.92**	−0.80	−0.74	−0.72
10	−9.02	−6.76	−5.18	−4.01	−3.20	−2.61	−2.10	−1.63	−1.27	−1.04	**−0.92**	−0.86	−0.83
11	−9.28	−7.01	−5.41	−4.21	−3.37	−2.77	−2.24	−1.75	−1.38	−1.14	−1.02	**−0.95**	−0.92
12	−9.59	−7.27	−5.63	−4.39	−3.53	−2.90	−2.35	−1.85	−1.46	−1.22	−1.09	−1.01	**−0.99**

Note: The percentiles in the column headings correspond to myopia prevalence among boys from senior kindergarten (grade 0) through third grade of high school (grade 12). Each row represents the estimated percentiles of non-cycloplegic SE for boys in that grade. Values in the main diagonal indicate grade-specific reference values for screening myopia. In each column, values above the main diagonal represent reference values at lower grades for predicting future myopia development at the corresponding higher grades. Values below the main diagonal represent predicted non-cycloplegic SE values through grade 12, assuming myopia onset occurs at a specific grade.

Abbreviation: SE=spherical equivalent.

TABLE 2. Grade-specific reference values of non-cycloplegic SE for screening and predicting myopia in girls.

Grade	Percentiles of non-cycloplegic SE (D)												
	1.0	**5.4**	**16.0**	**32.3**	**47.6**	**58.7**	**67.5**	**75.0**	**80.4**	**83.5**	**85.1**	**86.4**	**87.7**
0	**−1.73**	−1.05	−0.55	−0.15	0.12	0.31	0.45	0.59	0.70	0.76	0.80	0.84	0.87
1	−1.97	**−1.25**	−0.72	−0.31	−0.02	0.17	0.33	0.47	0.58	0.65	0.70	0.73	0.77
2	−2.58	−1.72	**−1.09**	−0.61	−0.27	−0.05	0.13	0.30	0.43	0.51	0.56	0.60	0.64
3	−3.70	−2.51	−1.69	**−1.06**	−0.63	−0.35	−0.13	0.08	0.24	0.35	0.40	0.45	0.51
4	−5.08	−3.44	−2.37	−1.57	**−1.04**	−0.69	−0.41	−0.16	0.04	0.17	0.24	0.30	0.37
5	−6.31	−4.29	−3.01	−2.06	−1.43	**−1.02**	−0.70	−0.40	−0.17	−0.02	0.06	0.13	0.21
6	−7.33	−5.06	−3.60	−2.54	−1.83	−1.37	**−1.00**	−0.67	−0.40	−0.24	−0.14	−0.06	0.02
7	−8.09	−5.71	−4.16	−3.01	−2.24	−1.73	−1.32	**−0.96**	−0.67	−0.48	−0.38	−0.29	−0.19
8	−8.57	−6.22	−4.63	−3.44	−2.62	−2.08	−1.64	−1.25	**−0.93**	−0.73	−0.62	−0.52	−0.42
9	−8.85	−6.61	−5.03	−3.81	−2.95	−2.38	−1.92	−1.50	−1.16	**−0.95**	−0.83	−0.72	−0.61
10	−9.02	−6.93	−5.38	−4.13	−3.25	−2.65	−2.16	−1.70	−1.34	−1.11	**−0.98**	−0.86	−0.74
11	−9.08	−7.18	−5.68	−4.43	−3.52	−2.89	−2.37	−1.88	−1.49	−1.24	−1.09	**−0.97**	−0.84
12	−9.10	−7.39	−5.96	−4.71	−3.77	−3.11	−2.56	−2.05	−1.62	−1.35	−1.20	−1.06	**−0.91**

Note: The percentiles in the column headings correspond to myopia prevalence among girls from senior kindergarten (grade 0) through third grade of high school (grade 12). Each row represents the estimated percentiles of non-cycloplegic SE for girls in that grade. Values in the main diagonal indicate grade-specific reference values for screening myopia. In each column, values above the main diagonal represent reference values at lower grades for predicting future myopia development at the corresponding higher grades. Values below the main diagonal represent predicted non-cycloplegic SE values through grade 12, assuming myopia onset occurs at a specific grade.

Abbreviation: SE=spherical equivalent.

exhibits a stronger correlation with myopia than age (*5*).

The reference values for predicting myopia onset by grade 12 are consistently higher for girls compared to boys, with this disparity diminishing as grade levels increase. In grades 0 to 3, girls' values average 0.17 D higher than boys', while by grade 11, this difference narrows to only 0.09 D. This pattern aligns with

TABLE 3. Grade-specific reference values of non-cycloplegic SE for screening and predicting high myopia in boys.

Grade	Percentiles of non-cycloplegic SE (D)								
	0.4	**1.0**	**1.9**	**3.3**	**5.0**	**6.7**	**8.3**	**10.0**	**11.6**
0	−2.13	−1.78	−1.52	−1.29	−1.11	−0.99	−0.89	−0.80	−0.73
1	−2.36	−1.99	−1.71	−1.47	−1.28	−1.15	−1.04	−0.95	−0.88
2	−3.05	−2.58	−2.24	−1.95	−1.72	−1.56	−1.44	−1.33	−1.24
3	−4.44	−3.72	−3.22	−2.80	−2.48	−2.26	−2.10	−1.95	−1.84
4	**−6.12**	−5.08	−4.38	−3.80	−3.37	−3.07	−2.85	−2.66	−2.51
5	−7.51	**−6.29**	−5.44	−4.74	−4.21	−3.86	−3.59	−3.36	−3.18
6	−8.64	−7.34	**−6.41**	−5.62	−5.03	−4.63	−4.32	−4.06	−3.85
7	−9.48	−8.16	−7.20	**−6.38**	−5.75	−5.32	−5.00	−4.72	−4.49
8	−9.98	−8.70	−7.75	−6.94	**−6.30**	−5.87	−5.53	−5.25	−5.02
9	−10.26	−9.03	−8.11	−7.32	−6.69	**−6.26**	−5.92	−5.63	−5.40
10	−10.46	−9.27	−8.38	−7.60	−6.98	−6.55	**−6.22**	−5.92	−5.69
11	−10.70	−9.53	−8.65	−7.86	−7.24	−6.80	−6.46	**−6.17**	−5.93
12	−11.02	−9.84	−8.94	−8.14	−7.51	−7.06	−6.71	−6.41	**−6.16**

Note: The percentiles in the column headings correspond to the prevalence of high myopia among boys from grade 4 (fourth grade of primary school) through grade 12 (third grade of high school). Each row represents the estimated percentiles of non-cycloplegic SE for boys in that grade. Values in the diagonal represent grade-specific reference values for screening high myopia. In each column, values above the diagonal represent reference values at lower grades for predicting future high myopia development at the corresponding higher grades. Values below the diagonal represent predicted non-cycloplegic SE values through grade 12, assuming high myopia onset occurs at a specific grade.
Abbreviation: SE=spherical equivalent.

TABLE 4. Grade-specific reference values of non-cycloplegic SE for screening and predicting high myopia in girls.

Grade	Percentiles of non-cycloplegic SE (D)								
	0.4	**0.9**	**1.6**	**2.8**	**4.6**	**6.6**	**8.6**	**10.8**	**13.2**
0	−2.08	−1.76	−1.54	−1.32	−1.12	−0.96	−0.84	−0.74	−0.64
1	−2.33	−1.99	−1.77	−1.53	−1.32	−1.16	−1.04	−0.93	−0.83
2	−3.02	−2.61	−2.34	−2.05	−1.80	−1.61	−1.46	−1.33	−1.21
3	−4.35	−3.75	−3.36	−2.97	−2.62	−2.37	−2.17	−2.00	−1.84
4	**−6.02**	−5.14	−4.60	−4.05	−3.59	−3.25	−2.99	−2.77	−2.57
5	−7.49	**−6.39**	−5.72	−5.05	−4.48	−4.07	−3.76	−3.49	−3.25
6	−8.62	−7.42	**−6.66**	−5.90	−5.27	−4.80	−4.45	−4.15	−3.88
7	−9.41	−8.18	−7.40	**−6.61**	−5.94	−5.44	−5.06	−4.74	−4.45
8	−9.84	−8.66	−7.90	−7.12	**−6.45**	−5.95	−5.56	−5.23	−4.94
9	−10.03	−8.93	−8.22	−7.48	−6.83	**−6.35**	−5.97	−5.64	−5.34
10	−10.06	−9.09	−8.44	−7.76	−7.14	−6.68	**−6.30**	−5.98	−5.69
11	−9.98	−9.15	−8.58	−7.95	−7.38	−6.94	−6.59	**−6.27**	−5.98
12	−9.87	−9.16	−8.66	−8.10	−7.58	−7.16	−6.83	−6.53	**−6.25**

Note: The percentiles in the column headings correspond to the prevalence of high myopia among girls from grade 4 (fourth grade of primary school) through grade 12 (third grade of high school). Each row represents the estimated percentiles of non-cycloplegic SE for girls in that grade. Values in the diagonal represent grade-specific reference values for screening high myopia. In each column, values above the diagonal represent reference values at lower grades for predicting future high myopia development at the corresponding higher grades. Values below the diagonal represent predicted non-cycloplegic SE values through grade 12, assuming high myopia onset occurs at a specific grade.
Abbreviation: SE=spherical equivalent.

previous research documenting that girls experience more rapid SE decline and higher myopia susceptibility than boys (*6*). These sex-based differences may be attributed to variations in near-work activities, outdoor exposure, and pubertal timing between boys and girls (*7–8*).

In a parallel study using identical methodology, we established cycloplegic SE reference values and observed that non-cycloplegic SE reference values were consistently lower than their cycloplegic counterparts, though this difference decreased with advancing grade levels. For grade 0 students, the discrepancy between cycloplegic and non-cycloplegic reference values for predicting myopia-free status by grade 12 was 0.84 D for boys and 0.93 D for girls. By grade 11, these differences diminished to 0.49 D and 0.41 D for boys and girls, respectively. These findings corroborate previous research demonstrating that the disparity between cycloplegic and non-cycloplegic refractive measurements is inversely related to age and myopic refractive error (*9*).

This study represents the first comprehensive effort to establish reference values for non-cycloplegic SE in predicting myopia using a methodology originally developed for body mass index assessment of thinness, overweight, and obesity in children (*10–11*). While our study introduces this novel approach and establishes reference values based on an extensive nationwide dataset with broad geographic coverage, several limitations warrant consideration. First, the participant sampling was not strictly randomized, and certain significant myopia-associated factors — including parental refractive error, eye care practices, and environmental lighting conditions — were not fully accounted for. Additionally, the timing of refractive measurements varied between morning (before classes) and afternoon (after prolonged study periods), with afternoon measurements typically showing greater myopic tendencies. Furthermore, the constant accommodation in younger students' eyes during non-cycloplegic refractive testing may introduce measurement errors, potentially affecting the predictive accuracy of reference values for lower-grade students. Nevertheless, the screening accuracy remained robust, exceeding 87.3% for myopia and 97.1% for high myopia across all grades.

The reference values proposed in this study offer valuable guidance for myopia screening and prediction in both public health initiatives and clinical settings, facilitating early identification and intervention for individuals at elevated risk for myopia. Moreover, the methodology employed here has potential applications beyond China in settings where childhood and adolescent myopia prevalence patterns demonstrate relative stability.

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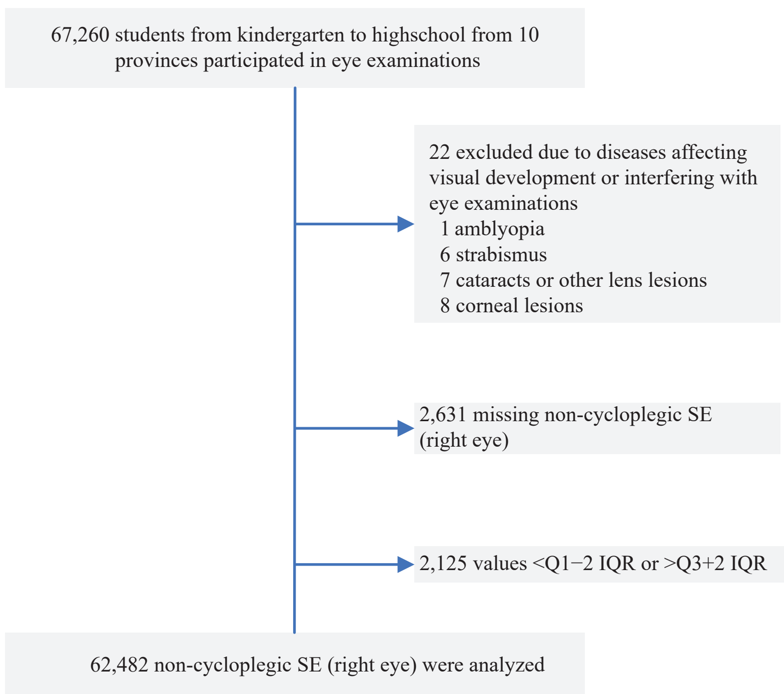
SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Estimated prevalence of myopia and high myopia at grade 0 to 12.

Grade	Myopia (%)			High myopia (%)		
	Total	Boy	Girl	Total	Boy	Girl
0	1.1	1.2	1.0	<0.1	<0.1	<0.1
1	5.5	5.8	5.4	<0.1	<0.1	<0.1
2	15.5	15.7	16.0	<0.1	<0.1	<0.1
3	31.0	29.5	32.3	<0.1	<0.1	<0.1
4	45.4	42.5	47.6	0.4	0.4	0.4
5	55.5	52.9	58.7	0.9	1.0	0.9
6	64.5	62.2	67.5	1.6	1.9	1.6
7	73.3	70.3	75.0	3.0	3.3	2.8
8	79.5	76.2	80.4	5.0	5.0	4.6
9	82.3	79.5	83.5	6.8	6.7	6.6
10	83.4	81.2	85.1	8.4	8.3	8.6
11	84.0	82.1	86.4	10.1	10.0	10.8
12	84.2	82.4	87.7	11.6	11.6	13.2

Note: The prevalence of myopia and high myopia at each grade was estimated using the Lambda-Mu-Sigma (LMS) method to determine the percentiles corresponding to –0.50 D and –6.00 D in the cycloplegic spherical equivalent (SE) for each grade. Complete methodological details regarding the estimation of smoothed myopia prevalence will be presented in a forthcoming study.



SUPPLEMENTARY FIGURE S1. Flow diagram of study population

Note: To minimize the impact of extreme outliers, we excluded values falling below Q1–2 IQR or above Q3+2 IQR from the analyses, where Q1 and Q3 represent the first and third quartiles of the grade-specific sample data, and IQR represents the interquartile range (Q3–Q1). This exclusion criterion resulted in the removal of 3.2% of observations.

Abbreviation: SE=spherical equivalent.

Methods and Applications

Development and Testing of Physical Literacy Scales for Chinese Elementary School Students — China, 2022

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ABSTRACT

Background: This study aimed to develop and validate test-based physical literacy scales (PLSs) for primary school students across different grades.

Methods: Data were collected through a field survey conducted from June 1 to July 31, 2022, involving 3,275 primary school students from four provinces in China. The questionnaires assessed four domains: physical knowledge, physical competence, physical motivation, and physical behavior. The Rasch model was employed for psychometric analysis.

Results: The variance explained by measures for the PLSs was 53.1%, 50.3%, and 54.7%, all exceeding the 50% threshold, confirming unidimensionality and robust internal consistency. This enabled effective differentiation among students with varying proficiency levels. The item-person map demonstrated optimal alignment between item difficulty and participant ability levels. Most items showed favorable fit statistics, with Infit mean square (MNSQ) and Outfit MNSQ values ranging between 0.5 and 1.5.

Conclusions: The PLSs demonstrate validity and reliability in measuring physical literacy among Chinese primary school students across four components: physical knowledge, physical competence, physical motivation, and physical behavior. The scales measure a unidimensional construct, supporting the use of summed total scores for assessment.

Physical literacy (PL) has evolved from the concept of health literacy (HL). The fundamental components of HL comprise emotional dimensions (motivation and confidence), physical dimensions (physical capability), and cognitive dimensions (knowledge and understanding) (*1*). PL represents a comprehensive construct that encompasses motivation, self-confidence, physical competence, motor skill execution, and active engagement in physical activities (*2*–*4*). Recent researches has extensively documented the benefits of physical activities, particularly those of moderate to vigorous intensity, for children and adolescents, including improvements in cardiovascular health, visual acuity, and mental well-being (*5*–*7*).

Despite these recognized benefits, the current state of physical activity among primary school students in China remains concerning, characterized by insufficient understanding of physical exercise and declining physical fitness (*8*). PL enables primary school students to develop fundamental comprehension of exercise and health, thereby fostering health-promoting behaviors and competencies (*9*). Students with strong PL competencies consistently demonstrate superior performance in physical activities. Therefore, PL assessment serves as a crucial tool for monitoring and evaluating the effectiveness of physical education among primary school students, ultimately informing and enhancing national-level policies and interventions.

Current research and assessment tool development for PL in China have predominantly focused on adolescent populations, particularly middle and high school students. A significant gap exists in the availability of standardized measurement tools for assessing PL among primary school students in China. This study addresses this gap by developing a comprehensive questionnaire specifically designed to measure PL in primary school students, taking into account the developmental characteristics of students across different grade levels.

METHODS

Study Population

This study employed a multistage cluster sampling approach conducted from June 1 to July 31, 2022. Three provinces were strategically selected to represent the eastern, central, and western regions of China, with one city randomly chosen from each province.

Additionally, a highly economically developed municipality in southern China was included to enhance regional representation. Within each selected city, we randomly selected one urban and one rural primary school. From each school, 1–2 classes were randomly sampled across three grade level groups (grades 1–2, 3–4, and 5–6). All students within the selected classes participated in the questionnaire survey, completing the instruments independently. The study yielded 3,275 valid questionnaires, distributed across educational stages as follows: 1,064 from grades 1–2, 1,069 from grades 3–4, and 1,142 from grades 5–6. Informed consent was obtained from all participants, and the study received ethical approval (Table 1).

Operationalization of the PL Model and Assessment

This study developed three grade-specific versions of the scale to align with children's cognitive development levels: PLS-Grade1–2 (physical literacy scale for elementary school students in grades 1–2), PLS-Grade 3–4 (physical literacy scale for elementary school students in grades 3–4), and PLS-Grade5–6 (physical literacy scale for elementary school students in grades 5–6). The scale's framework was constructed based on four fundamental dimensions of children's HL derived from existing Chinese policy documents and guidelines: knowledge, physical participation, physical competence, and physical motivation (Table 2).

Each version of the scale consists of two components: a Personal Information Questionnaire and a Physical Literacy Measurement Scale. The Personal Information Questionnaire comprises eight items collecting data on student demographics and behavioral characteristics: name, gender, age, grade, ethnicity, nearsightedness status, physical activity level, and internet usage patterns. The Physical Literacy Measurement Scale evaluates the four dimensions of children's PL using a 100-point scoring system. Dimensional weights were predetermined through Delphi expert consultation to ensure appropriate score

TABLE 1. Sociodemographic characteristics of the students (*N*=3,275).

Demographics	Frequency			Missing
	Grade 1–2 *n* (%)	Grade 3–4 *n* (%)	Grade 5–6 *n* (%)	
Gender				82
Boys	517 (49.6)	514 (49.2)	579 (52.3)	
Girls	525 (50.4)	530 (50.8)	528 (47.7)	
Grade				32
1/3/5	461 (43.9)	431 (40.8)	527 (46.4)	
2/4/6	590 (56.1)	625 (59.2)	609 (53.6)	
Ethnicity				41
Han	898 (86.1)	953 (89.7)	1,009 (89.4)	
Minority	145 (13.9)	109 (10.3)	120 (10.6)	
Nearsightedness				189
Yes	87 (8.2)	266 (26.5)	387 (38.1)	
No	897 (84.3)	667 (66.4)	572 (56.2)	
Unawareness	80 (7.5)	72 (7.1)	58 (5.7)	
Total	1,064 (100)	1,069 (100)	1,142 (100)	

TABLE 2. Summary structure and content classification of the three-vision scales.

Dimension	PLS-Grade	Items	Answer
Physical knowledge	1–2	B1–B10	Yes/No
	3–4	B1–B10	
	5–6	B1–B15	
Physical participation	1–2	D01C–D10C	Likert four-level scale (Never/1 to 3 times/4 to 6 times /Everyday)
	3–4	D01C–D12C	
	5–6	C01C–C14C	
		C01D–C14D	Likert five-level scale (Less than 0.5 hours/ 0.5 to 1 hour/1 to 2 hours/ more than 2 hours)
Physical motivation	1–2	C1–C10	Yes/No
	3–4	C1–C12	
	5–6	D1–D15	Likert five-level scale
Physical competence	1–2	D01B–D10B	Yes/No
	3–4	D01B–D12B	
	5–6	C01B–C14B	

Abbreviation: PLS=physical literacy scales.

allocation across components.

Physical Knowledge: The item banks were customized according to students' comprehension levels across different grades. For grades 1–4, 10 items were selected, while 15 items were chosen for grades 5–6. Each item consists of a true/false statement designed to assess children's understanding of physical activity, sedentary behavior recommendations, health perspectives, and safety awareness during physical activities (Table 3).

Physical Competence: The physical competence domain evaluates proficiency in various physical activities through capability-based questions (e.g., "Can you perform this activity?"). Following expert panel discussions, we developed grade-specific activity categories. For grades 1–2, we included 10 categories spanning leisure activities (e.g., shuttlecock kicking), moderate-intensity activities (cycling, gymnastics, roller skating, taekwondo), and high-intensity activities (dance, swimming, running, table tennis). The grades 3–4 questionnaire incorporated soccer and badminton as additional activities. For grades 5–6, we expanded the assessment to include sit-ups/pull-ups, mountain climbing, martial arts, and consolidated ball sports into two choice categories: one between basketball, soccer, or volleyball, and another between badminton, table tennis, or tennis. The final item counts were 10 for PLS-Grade1–2, 12 for PLS-Grade3–4, and 14 for PLS-Grade5–6.

Physical Participation

The physical participation domain evaluates weekly exercise activities across varying intensities and durations. Students in grades 1–4 respond using a four-point Likert scale, while grades 5–6 students answer questions structured on a four-point Likert scale. The number of items corresponds to the physical competences listed in the questionnaire: PLS-Grade 1–2 contains 10 items, PLS-Grade3–4 comprises 12 items, and PLS-Grade5–6 includes 14 items.

Physical Motivation

The Children's Self-Perception of Adequacy in and Predilection for Physical Activity (CSAPPA) Scale (*10*) was utilized to assess children's perceived competence in physical activities and their inclination toward

TABLE 3. Items for the physical knowledge and physical motivation dimensions.

Dimension	Grades	Item number	Item	Question type
Physical knowledge	1–2	B1–B2	The concept of physical activity	Yes/No
		B3	Benefits of physical activity	
		B4–B5	Knowledge about physical activity safety	
		B6	The concept of health	
		B7	Whether air pollution should continue to exercise	
		B8–B9	The dangers of sitting for a long time	
		B10	Knowledge about the amount of exercise	
	3–4	B1–B2	The concept of physical activity	Yes/No
		B3	Benefits of physical activity	
		B4–B5	Knowledge about physical activity safety	
		B6	The concept of health	
		B7	Whether to exercise under air pollution	
		B8–B9	The dangers of sitting for a long time	
		B10	Knowledge about the amount of exercise	
	5–6	B1–B2	The concept of physical activity	Yes/No
		B3	Benefits of physical activity	
		B4, B6–B7	Knowledge about physical activity safety	
		B5	Type of physical activity	
		B8	Knowledge about the amount of exercise	
		B9–B10	Whether to exercise under air pollution	
		B11–B14	The dangers of sitting for a long time	
		B15	The concept of health	

Continued

Dimension	Grades	Item number	Item	Question type
Physical motivation	1–2	C1	In order to strengthen physical fitness and get sick less	Judgment question
		C2	To bring me joy	
		C3	To learn new sport skills	
		C4	Like to meet new challenges	
		C5	To maintain good health	
		C6	In order to complete the sports test in school	
		C7	To meet new friends	
		C8	To look better for my own appearance	
		C9	Due to its inherent amusement	
		C10	Because exercise is important for me	
	3–4	C1	In order to strengthen physical fitness, get sick less	Judgment question
		C2	To bring me joy	
		C3	To learn new sport skills	
		C4	Like to meet new challenges	
		C5	To maintain good health	
		C6	In order to complete the sports test in school	
		C7	My friend wants me to exercise more	
		C8	To look better for my own appearance	
		C9	Due to its inherent amusement	
		C10	To meet new friends	
		C11	In order to get good results in sports tests of school	
		C12	Because exercise is important for me	
	5–6	D1	Because it is in line with life goals	Likert five-level scale
		D2	To relieve stress	
		D3	To control weight and improve body shape	
		D4	To bring me joy	
		D5	Because I enjoy of the process of exercise	
		D6	To maintain health	
		D7	To look better for my own appearance	
		D8	To maintain relationships	
		D9	To learn new sport skills	
		D10	Because everyone thinks I should exercise	
		D11	Because of the requirements of teachers and parents	
		D12	In order to get good results in sports tests	
		D13	Because of the deep love for sports	
		D14	Due to its inherent amusement	
		D15	Because of the importance of health	

participation. All scale items were adapted into age-appropriate language to ensure comprehension by adolescent participants. The PLS-Grade1–2 and PLS-Grade3–4 utilize true/false questions, with 10 questions per grade level. The PLS-Grade5–6 employs a five-point Likert scale comprising 15 questions (Table 3).

Statistical Analysis

To ensure data quality and independence, each class was assigned a dedicated investigator for the duration of the study. Students completed the questionnaires independently without teacher influence, while both the survey administrator and class teacher supervised the process to verify complete and accurate completion of all questionnaires.

The measurement methodology was primarily guided by item response theory (IRT). Analysis was conducted using Winsteps software (version 3.66.0; https://winsteps.com/index.htm) to evaluate both dichotomous and multi-classification items. Items that failed to meet Rasch model criteria were either adjusted or eliminated as necessary.

RESULTS

Item Summary Statistics

Analysis of participant ability difficulty scores revealed mean values of −1.65, −1.06, −1.26, and −0.27, indicating that the items presented considerable challenge to participants. The Rasch model evaluation, utilizing Infit MNSQ and Outfit MNSQ average values, demonstrated optimal overall fit with values consistently falling between 0.5 and 1.5. These results indicate strong alignment between the three questionnaires and the ideal model, confirming robust data consistency (Table 4).

Unidimensionality

The variance explained by the measures across the three questionnaires was 53.1%, 50.3%, and 54.7%, respectively, all exceeding the 50% threshold. These results confirm unidimensionality, indicating that the items within each scale effectively measure a single, cohesive domain.

Item Person Map

The distribution of item difficulty and participant ability levels varied across grade groups. For grades 1–2, item difficulty spanned from −3 to 3 logit units, while participant ability levels ranged from -3 to 5 logit units. In grades 3–4, item difficulty ranged from -4 to 3 logit units, with participant ability levels distributed between −2 and 5 logit units. For grades 5–6, item difficulty extended from −4 to 3 logit units, while participant ability levels ranged from −2 to 4 logit units (Figure 1A–C). Across all three questionnaires, the item difficulty distribution demonstrated optimal alignment with participant ability levels.

Item Fit Statistical Analysis

Analysis of item fit statistics revealed robust measurement properties across all three scales. For PLS-Grade1–2, the Infit mean square statistics ranged from 0.82 to 1.31 with a mean of 1.00, while Outfit mean square values spanned from 0.62 to 1.78,

TABLE 4. Item summary statistics (*N*=3,275).

Psychometric attribute	PLS-Grade1–2	PLS-Grade3–4	PLS-Grade5–6
Number of item	40	46	72
Measure (Person)	1.68	1.14	0.40
Measure (Item)	0	0	0
Reliability			
Person reliability	0.81	0.81	0.89
Item reliability	1.00	1.00	1.00
Separation			
Person separation	2.04	2.09	2.86
Item separation	14.23	15.41	21.25
Item-fit statistics			
Infit MNSQ			
Mean square	1.00	1.01	1.11
Standard Deviation	0.10	0.09	0.46
ZSTD	−0.1	0.0	0.4
Outfit MNSQ			
Mmean square	1.04	1.12	1.17
Standard Deviation	0.28	0.29	0.56
ZSTD	0.3	0.8	0.5

Abbreviation: PLS=physical literacy scales; MNSQ=mean square; ZSTD=Z-standardized mean.

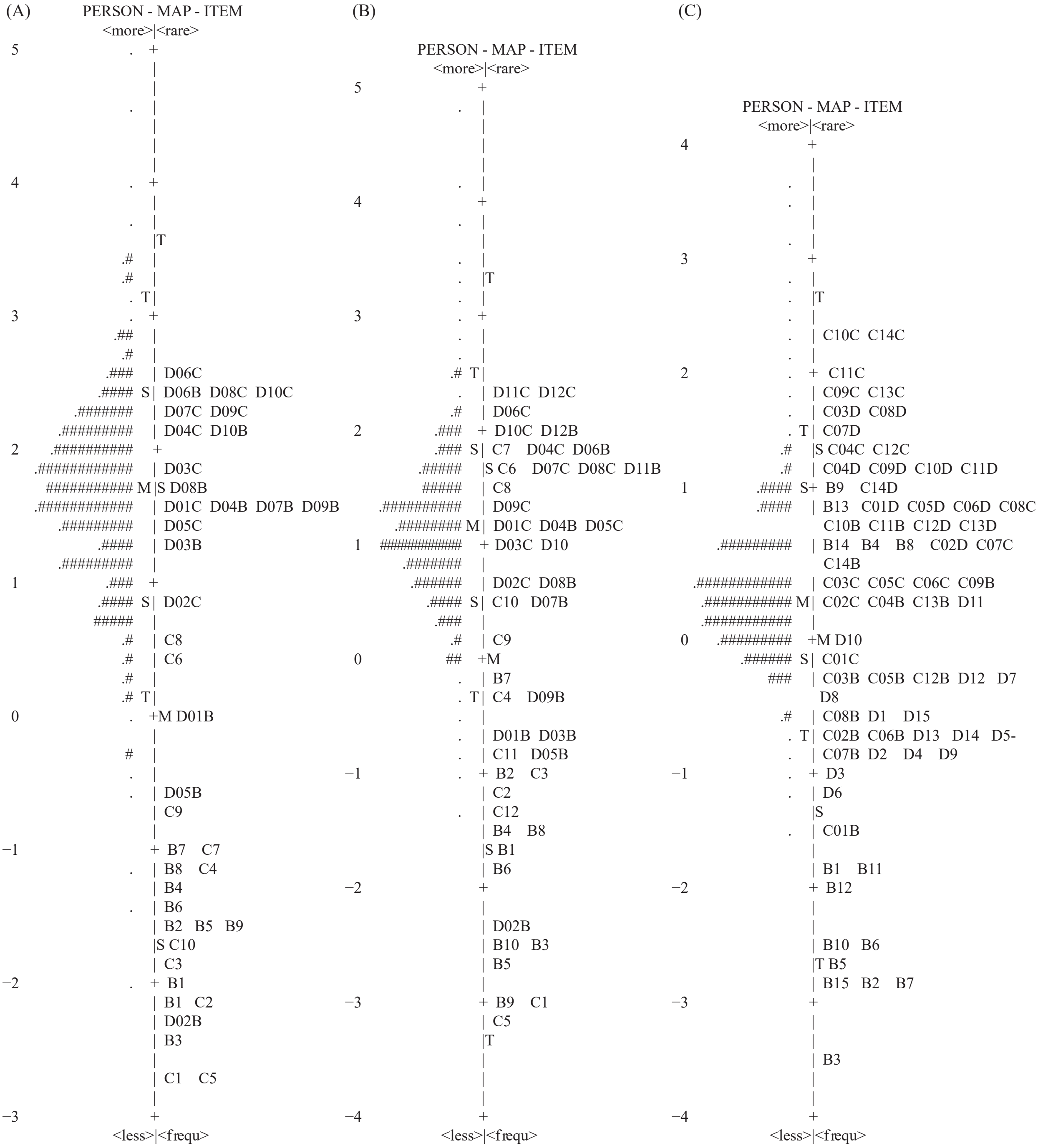

FIGURE 1. The distribution map of item difficulty and participant ability levels of (A) PLS-Grade1–2; (B) PLS-Grade3–4; and (C) PLS-Grade5–6.
Note: The left side of the chart shows the participants' ability levels and the right side displays the item difficulty levels. Each "#" means 8. Each "." means 1 to 7.
Abbreviation: PLS=physical literacy scales.

averaging 1.04. PLS-Grade3–4 demonstrated Infit MNSQ values between 0.79 and 1.34 (mean=1.01) and Outfit MNSQ values from 0.81 to 2.16 (mean=1.12). For PLS-Grade5–6, Infit MNSQ values ranged from 0.32 to 2.18 (mean=1.11), with corresponding Outfit MNSQ values spanning 0.37 to 2.54 (mean=1.17) (Supplementary Table S1, available at https://weekly.chinacdc.cn/).

DISCUSSION

The validation of questionnaire quality yielded robust results. The item reliability coefficients across all four grade levels achieved a value of 1, with item separation values substantially exceeding 3. These findings demonstrate exceptional internal consistency within the questionnaire and validate the hierarchical structure of item difficulty levels. Furthermore, the questionnaire effectively discriminates among students with varying proficiency levels. The unidimensionality test revealed that all items across the three questionnaires met the necessary criteria, justifying subsequent Rasch model analysis. The item-person map demonstrates optimal alignment between the average item difficulty and respondents' ability levels, with items of varying difficulty distributed evenly across the scale. This distribution effectively accommodates primary school students across the spectrum of health literacy levels. Statistical analyses of all three questionnaires indicated favorable overall fit, showing strong concordance with the ideal model.

From an implementation perspective, our approach effectively addresses the varying cognitive capacities among primary school students while enabling precise assessment of their PL development. The questionnaires were strategically designed with grade-appropriate item counts, incorporating more questions for higher-grade students to maintain engagement throughout the measurement process. To accommodate younger students' developing comprehension abilities, their questionnaires featured simplified formats, such as true/false questions. Conversely, five-point Likert scale items were implemented for higher-grade students to comprehensively capture physical activity motivation factors. Additionally, the questionnaires employed grade-specific language to address variations in comprehension levels across age groups. This PL measurement scale, grounded in a thorough understanding of student characteristics, enhances both scientific rigor and practical utility through its hierarchical design and differentiated approach. These methodological insights offer valuable guidance for future PL measurement tool development.

Our study has several limitations. First, the reliance on primary school students' voluntary responses may introduce inherent participant subjectivity biases (*11*). Future studies should consider diverse data collection methods, such as parental or teacher assistance in questionnaire interpretation, to mitigate potential cognitive limitations-related subjectivity. Second, our use of cluster sampling may have resulted in population underrepresentation (*12*). We recommend that future research enhance survey methodology to reduce bias, moderately decrease scale difficulty, and expand sample size.

Conflicts of interests: No conflicts of interest.

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Ethical statements: This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were reviewed and approved by the Institutional Review Board (IRB) of the Chinese Academy of Medical Sciences and Peking Union Medical College. Approval was granted with protocol number CAMS&PUMC-IEC-2022-026. Obtained written informed consent from all study participants. Obtained consent from parents or guardians.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE S1. Outfit and Infit mean square statistics for individual items.

PLS-Grade	Item	Measure	SE	INFIT		OUTFIT		PT-Measure corr.
				MNSQ	ZSTD	MNSQ	ZSTD	
1–2	D06C	2.63	0.04	0.82	−3.4	0.73	−3.4	0.58
	D10C	2.48	0.04	1.28	5.2	1.62	6.7	0.44
	D08C	2.43	0.04	0.92	−1.6	1.01	0.1	0.52
	D06B	2.43	0.07	0.91	−3.4	0.92	−2.0	0.41
	D07C	2.29	0.03	0.88	−2.7	0.93	−0.9	0.56
	D09C	2.27	0.03	0.86	−3.4	0.94	−0.8	0.58
	D10B	2.14	0.07	1.00	0.2	1.04	1.2	0.31
	D04C	2.11	0.03	1.29	6.8	1.31	4.4	0.46
	D03C	1.92	0.03	1.31	7.7	1.47	6.9	0.46
	D08B	1.70	0.07	0.98	−0.8	0.98	−0.6	0.34
	D07B	1.64	0.07	0.94	−3.4	0.92	−3.0	0.40
	D04B	1.61	0.07	0.99	−0.4	1.0	−0.2	0.33
	D01C	1.57	0.03	1.09	2.3	1.17	2.8	0.51
	D09B	1.54	0.07	0.90	−5.0	0.88	−4.5	0.44
	D05C	1.36	0.03	0.92	−2.1	0.97	−0.5	0.54
	D03B	1.24	0.07	0.94	−2.9	0.93	−2.3	0.40
	D02C	0.86	0.04	0.98	−0.4	1.26	2.9	0.52
	C8	0.50	0.08	1.01	0.4	1.02	0.4	0.28
	C6	0.38	0.08	1.11	2.7	1.41	6.4	0.12
	D01B	−0.04	0.09	1.03	0.5	1.00	0	0.25
	D05B	−0.52	0.10	0.97	−0.4	0.90	−1.0	0.29
	C9	−0.78	0.11	0.97	−0.3	0.88	−1.0	0.28
	C7	−0.97	0.12	0.98	−0.2	0.89	−0.9	0.26
	B7	−1.07	0.12	1.04	0.5	1.49	3.1	0.13
	B8	−1.13	0.13	0.98	−0.1	0.94	−0.4	0.23
	C4	−1.20	0.13	0.95	−0.4	0.84	−1.1	0.28
	B4	−1.35	0.14	0.99	0	1.10	0.6	0.2
	B6	−1.49	0.14	1.07	0.6	1.78	3.8	0.02
	B2	−1.56	0.15	0.95	−0.4	0.68	−2.0	0.28
	B5	−1.56	0.15	1.05	0.4	1.40	2.1	0.10
	B9	−1.63	0.15	0.98	−0.1	0.97	−0.1	0.23
	C10	−1.65	0.15	0.92	−0.6	0.69	−1.8	0.30
	C3	−1.83	0.17	0.94	−0.3	0.63	−2.1	0.27
	B1	−1.98	0.18	1.02	0.2	1.09	0.5	0.13
	C2	−2.08	0.19	0.95	−0.2	0.90	−0.4	0.21
	B10	−2.15	0.19	0.98	0	1.69	2.5	0.15
	D02B	−2.31	0.21	0.97	−0.1	0.90	−0.3	0.17
	B3	−2.39	0.21	1.02	0.2	0.91	−0.2	0.13
	C1	−2.71	0.25	0.94	−0.2	0.62	−1.3	0.21
	C5	−2.71	0.25	0.94	−0.2	0.79	−0.6	0.19

Continued

PLS-Grade	Item	Measure	SE	INFIT		OUTFIT		PT-Measure corr.
				MNSQ	ZSTD	MNSQ	ZSTD	
3–4	D12C	2.4	0.05	1.34	5.2	1.02	2.7	0.49
	D11C	2.27	0.04	1.06	1.0	0.96	−0.5	0.55
	D06C	2.25	0.04	0.96	−0.8	0.87	−1.9	0.59
	D12B	2.07	0.07	0.98	−0.7	0.97	−0.8	0.33
	D10C	2.05	0.04	0.87	−2.6	0.93	−1.1	0.59
	D04C	1.89	0.04	1.20	4.0	1.18	3.0	0.47
	D06B	1.87	0.07	0.95	−2	0.91	−2.5	0.38
	C7	1.77	0.07	1.04	1.5	1.05	1.6	0.24
	D07C	1.69	0.04	0.93	−1.8	0.93	−1.3	0.54
	C6	1.68	0.07	1.07	2.7	1.11	3.6	0.20
	D08C	1.66	0.04	0.86	−3.4	0.84	−3.2	0.60
	D11B	1.61	0.07	0.97	−1.3	0.97	−1.2	0.34
	C8	1.55	0.07	1.10	4.7	1.13	4.6	0.15
	D09C	1.29	0.03	0.79	−6.1	0.81	−4.4	0.58
	D05C	1.21	0.03	0.84	−4.7	0.85	−3.4	0.54
	D04B	1.17	0.07	1.04	2.2	1.04	1.6	0.25
	D01C	1.10	0.03	0.98	−0.4	1.09	2.0	0.48
	D10B	1.00	0.07	0.95	−3.1	0.94	−2.5	0.37
	D03C	0.96	0.03	1.19	5.1	1.26	5.3	0.45
	D08B	0.67	0.07	0.96	−1.7	0.96	−1.2	0.34
	D02C	0.61	0.03	0.97	−0.8	1.01	0.2	0.44
	D07B	0.51	0.07	1.02	0.8	1.04	1.2	0.25
	C10	0.43	0.07	1.00	0.1	1.05	1.3	0.27
	C9	0.13	0.07	1.02	0.6	1.09	1.8	0.23
	B7	−0.12	0.08	1.11	2.7	1.27	4.6	0.07
	C4	−0.40	0.08	0.99	−0.2	1.08	1.2	0.24
	D09B	−0.41	0.08	0.95	−1.1	0.95	−0.8	0.31
	D01B	−0.62	0.09	1.03	0.5	1.15	1.9	0.18
	D03B	−0.66	0.09	0.97	−0.5	0.98	−0.2	0.26
	C11	−0.79	0.09	1.01	0.1	1.04	0.5	0.20
	D05B	−0.79	0.09	0.98	−0.2	1.00	0	0.23
	C3	−0.94	0.1	0.99	−0.1	1.03	0.4	0.21
	B2	−1.00	0.1	1.04	0.6	1.15	1.5	0.13
	C2	−1.09	0.1	0.97	−0.4	0.96	−0.3	0.24
	C12	−1.27	0.11	0.98	−0.2	0.95	−0.4	0.21
	B8	−1.44	0.12	1.05	0.5	1.74	5.0	0.04
	B4	−1.52	0.12	1.07	0.7	1.85	5.3	−0.02
	B1	−1.67	0.13	1.00	0.1	1.24	1.6	0.13
	B6	−1.81	0.13	1.02	0.2	1.05	0.4	0.12
	D02B	−2.41	0.17	1.00	0	1.27	1.3	0.09
	B3	−2.47	0.18	1.02	0.2	1.19	0.9	0.08
	B10	−2.50	0.18	0.98	0	0.9	−0.4	0.16

Continued

PLS-Grade	Item	Measure	SE	INFIT		OUTFIT		PT-Measure corr.
				MNSQ	ZSTD	MNSQ	ZSTD	
	B5	−2.72	0.2	1.03	0.2	2.07	3.6	−0.01
	B9	−2.99	0.23	1.02	0.2	2.16	3.4	−0.03
	C1	−2.99	0.23	0.99	0	0.82	−0.6	0.13
	C5	−3.22	0.25	1.0	0.1	1.34	1.2	0.07
5–6	C14C	2.31	0.06	1.15	2	1.04	0.6	0.48
	C10C	2.28	0.06	1.27	3.5	1.13	1.7	0.50
	C11C	2.04	0.05	1.32	4.4	1.33	4.2	0.46
	C09C	1.88	0.05	1.28	4.0	1.24	3.3	0.46
	C13C	1.86	0.05	0.99	−0.1	0.97	−0.5	0.53
	C08D	1.66	0.05	1.18	3.4	1.17	3.2	0.34
	C03D	1.64	0.05	1.20	3.7	1.18	3.5	0.35
	C07D	1.44	0.05	1.19	3.4	1.17	3.2	0.41
	C04C	1.35	0.04	1.38	6.5	1.40	6.3	0.29
	C12C	1.34	0.04	0.77	−4.8	0.80	−3.9	0.50
	C11D	1.22	0.05	0.65	−7.4	0.64	−7.7	0.34
	C09D	1.19	0.05	0.72	−5.7	0.71	−6.2	0.34
	C10D	1.13	0.05	0.69	−6.6	0.66	−7.1	0.34
	C04D	1.13	0.05	1.13	2.4	1.12	2.2	0.22
	C14D	1.08	0.04	0.64	−7.8	0.61	−8.4	0.35
	B9	1.02	0.05	0.58	−9.9	0.61	−9.9	0.02
	C13D	0.91	0.04	0.75	−5.3	0.73	−5.6	0.40
	C01D	0.9	0.04	1.19	3.5	1.18	3.2	0.48
	C06D	0.89	0.04	1.16	3	1.17	3.1	0.42
	C10B	0.88	0.04	1	−0.1	0.99	−0.2	0.39
	C11B	0.84	0.04	0.98	−0.5	0.97	−0.5	0.4.0
	B13	0.84	0.05	0.42	−9.9	0.45	−9.9	0.13
	C08C	0.81	0.03	0.8	−5.5	0.79	−5.0	0.49
	C05D	0.77	0.04	1.17	3.2	1.14	2.7	0.44
	C12D	0.77	0.04	1.00	0	1.00	0	0.41
	C02D	0.67	0.04	1.12	2.5	1.12	2.2	0.39
	B4	0.67	0.05	0.34	−9.9	0.39	−9.9	0.01
	B14	0.66	0.05	0.32	−9.9	0.37	−9.9	0.05
	C14	0.66	0.03	1.05	1.8	1.08	1.6	0.34
	B8	0.65	0.05	0.34	−9.9	0.4	−9.9	−0.05
	C07C	0.62	0.03	0.80	−5.8	0.8	−5.3	0.41
	C09B	0.55	0.03	1.07	2.8	1.11	2.1	0.32
	C06C	0.54	0.03	0.80	−6.1	0.8	−5.3	0.47
	C05C	0.53	0.03	0.93	−2.1	0.92	−2.0	0.48
	C03C	0.48	0.03	1.33	8.6	1.35	8.1	0.26
	C02C	0.39	0.03	1.05	1.6	1.07	1.8	0.37
	C04B	0.35	0.03	1.17	7.5	1.41	6.2	0.19
	C13B	0.35	0.03	1.04	1.9	1.06	1.0	0.33

Continued

PLS-Grade	Item	Measure	SE	INFIT		OUTFIT		PT-Measure corr.
				MNSQ	ZSTD	MNSQ	ZSTD	
	D11	0.29	0.03	1.21	5.5	1.28	6.8	0.35
	D10	−0.03	0.03	1.04	0.9	1.09	2.1	0.39
	C01C	−0.12	0.03	0.79	−6.9	0.83	−4.5	0.39
	D7	−0.25	0.03	1.14	3.2	1.28	5.6	0.35
	D12	−0.25	0.03	1.12	2.8	1.21	4.3	0.37
	C03B	−0.31	0.04	1.12	3.0	1.93	7.6	0.14
	C05B	−0.34	0.04	1.00	−0.1	0.89	−1.1	0.31
	D8	−0.35	0.03	1.06	1.5	1.08	1.7	0.41
	C12B	−0.35	0.04	1.00	0.1	1.01	0.2	0.29
	D1	−0.54	0.03	0.74	−6.1	0.73	−5.8	0.51
	C08B	−0.57	0.04	0.98	−0.3	1.28	2.2	0.27
	D15	−0.58	0.03	0.86	−3.0	0.89	−2.2	0.46
	D5	−0.66	0.03	0.85	−3.3	0.82	−3.6	0.49
	C02B	−0.68	0.05	1.05	0.8	1.21	1.6	0.19
	D14	−0.69	0.04	0.86	−3.0	0.86	−2.6	0.50
	D13	−0.70	0.04	0.84	−3.3	0.83	−3.2	0.51
	C06B	−0.73	0.05	0.99	−0.2	0.88	−0.9	0.26
	D9	−0.75	0.04	0.85	−3.1	0.89	−2.1	0.43
	D4	−0.76	0.04	0.78	−4.6	0.73	−5.4	0.51
	D2	−0.80	0.04	0.67	−7.1	0.65	−7.0	0.51
	C07B	−0.92	0.06	1.02	0.3	1.1	0.7	0.18
	D3	−1.08	0.04	0.86	−2.5	0.82	−3.0	0.43
	D6	−1.11	0.04	0.79	−3.9	0.74	−4.5	0.43
	C01B	−1.55	0.09	0.97	−0.1	1.35	1.3	0.14
	B11	−1.85	0.07	2.18	9.9	2.5	9.9	0.08
	B1	−1.87	0.07	2.18	9.9	2.34	9.9	0.10
	B12	−2.06	0.07	2.08	9.9	2.2	9.9	0.18
	B6	−2.48	0.08	2.13	9.9	2.54	9.9	0.05
	B10	−2.50	0.08	2.09	9.9	2.30	9.9	0.10
	B5	−2.65	0.09	2.08	9.9	2.35	9.9	0.09
	B7	−2.81	0.09	2.07	9.9	2.35	9.9	0.09
	B2	−2.88	0.10	2.09	9.9	2.53	9.9	0.04
	B15	−2.88	0.10	2.07	9.9	2.44	9.9	0.07
	B3	−3.48	0.12	2.01	7.0	2.33	7.4	0.11

Abbreviation: PLS=physical literacy scales; SE=standard error; PT-Measure corr.=point measure correlation; MNSQ=mean square; ZSTD= Z-standardized mean.

Recollections

Implementation of Universal Newborn Hearing Screening and Analysis of School Enrollment Among Hearing-Impaired Students in China

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ABSTRACT

Universal newborn hearing screening (UNHS) is recognized as the most effective strategy for early detection of congenital hearing loss; however, screening coverage remains inadequate in many countries. In China, newborn hearing screening has been implemented for over two decades. To evaluate our policies and practices during this period and assess resource equity, health impacts, and future challenges, we conducted a nationwide survey focusing on newborn hearing screening coverage, the number of special schools for deaf-mutes, and the proportion of hearing-impaired students in mainstream education. From 2001 to 2020, China's UNHS program coverage increased from 10.9% to 94.3%, while the proportion of hearing-impaired students in mainstream education rose from 24.8% to 57.5%. Concurrently, the number of hearing-impaired students in special schools decreased from 76,554 to 34,945, and the number of special schools for deaf-mutes declined from 639 to 389. Through the implementation of the UNHS program, China has made substantial progress in improving newborn hearing health, yielding long-term benefits for those with congenital hearing loss. However, targeted resource allocation and the establishment of a national platform remain priorities for future development. Our experience may provide valuable insights for similar settings.

Congenital hearing loss represents a critical public health challenge, affecting 1 to 3 per 1,000 neonates in the general population (*1*), with prevalence rates escalating to 2% to 4% among those with established risk factors (*2*). Early-onset hearing impairment significantly impacts speech and language development. Without early intervention, congenital hearing loss frequently progresses to profound deafness, leading to substantial learning difficulties and emotional and social developmental challenges (*3–4*). However, when detection, diagnosis, intervention, and rehabilitation are implemented early, individuals with hearing impairment can achieve developmental outcomes comparable to their normal-hearing peers, facilitating social integration and reducing both familial and societal burden.

Universal Newborn Hearing Screening (UNHS) has emerged as the most effective strategy for early detection of congenital hearing loss (*5*). While some developed nations have achieved UNHS screening rates as high as 97.7% (*6*), the global landscape reveals significant disparities. Only 41 countries have attained coverage exceeding 85%, while at least 64 countries report coverage rates below 1% (*7*). As UNHS systems mature, an increasing number of hearing-impaired children receive timely interventions, enabling their integration into mainstream educational settings rather than specialized institutions. This shift in mainstream school enrollment patterns reflects various social, economic, and educational reforms, corresponding to UNHS development and serving as an indicator of intervention outcomes.

China, as a developing nation with one of the world's largest populations, has made remarkable progress in UNHS coverage through sustained governmental initiatives over two decades. The country established its first national technical specification for newborn hearing screening in 2004, followed by the launch of a targeted national newborn disease screening project in 2014 to enhance screening rates in economically disadvantaged regions (Supplementary Figure S1, available at https://weekly.chinacdc.cn/). This study examines the policy implementation and practical outcomes of UNHS in China across the past two decades, with particular emphasis on resource equity, health impacts (including screening coverage and mainstream education integration of hearing-impaired students), and future challenges. The insights gained from this experience may prove valuable for similar healthcare contexts globally.

This study encompassed 31 provincial-level administrative divisions (PLADs), excluding Hong Kong Special Administrative Region (SAR); Macau SAR; and Taiwan, China, due to data unavailability. Data on the UNHS program were collected in 2021 through questionnaires distributed to 31 provincial health committees by the National Health Commission (NHC) of China. Educational data were obtained from the Ministry of Education (MOE) of China website (http://www.moe.gov.cn/jyb_sjzl/moe_560/). The study received approval from the ethics committee of Shanghai Ninth People's Hospital Shanghai Jiao Tong University (SH9H-2022-T377-1).

History and Policy of UNHS in China

China initiated the UNHS program in the late 1990s, achieving comprehensive coverage across all PLADs by 2014. According to the National Center for Birth Defects Monitoring of China, national coverage increased substantially from 29.9% in 2008 to 86.5% in 2016 (*8*). The program's development can be categorized into three distinct phases: the exploration and pilot stage (1989–2000), the launch and promotion stage (2001–2014), and the nationwide implementation stage (2015-present) (Supplementary Figure S1).

The Chinese UNHS protocol follows a two-step screening process: initial screening after birth and repeat screening within 42 days. Distortion product otoacoustic emissions (DPOAE) serve as the primary screening method, followed by hearing diagnosis within 3 months, intervention within 6 months, and rehabilitation from 6 months to 6 years of age, culminating in enrollment for compulsory education for ages 6–14 (Supplementary Figure S2, available at https://weekly.chinacdc.cn/). China's compulsory education law, enacted in 1986, mandates nine years of schooling, encompassing elementary (grades 1–6) and middle school (grades 7–9). Educational options for hearing-impaired students include special education schools, attached classes, regular classes, and 'home delivery' teaching (http://www.moe.gov.cn/). With UNHS implementation, an increasing number of hearing-impaired students now attend regular classes rather than special schools or classes. However, to our knowledge, the enrollment proportion among hearing-impaired students in China has not been previously documented in the literature.

Resource Equity

The Gini coefficient and Lorenz curve, well-established metrics for quantifying inequality, were employed to evaluate the distribution equity of healthcare services (including screening institutions and pediatric hearing diagnosis and treatment centers) and educational resources (including rehabilitation institutions and specialized schools for deaf-mutes) (Figure 1). Using each PLAD as an analytical unit, we conducted a nationwide equity assessment. The X-axis represents the cumulative proportion of births (in 2020, stratified by PLADs), while the Y-axis represents the cumulative proportion of corresponding resources.

The Gini coefficient ranges from 0 to 1, with higher values indicating greater inequality. Conventionally, coefficients below 0.2 indicate absolute equality, 0.2–0.3 relative equality, 0.3–0.4 adequate equality, 0.4–0.5 relative inequality, and above 0.5 severe inequality. Graphically, the coefficient represents the ratio between two areas: the area between the Lorenz curve (blue) and the line of perfect equality (green), and the total area beneath the line of perfect equality. A lower Gini coefficient indicates more equitable resource distribution relative to birth population across PLADs. As of 2020, China's infrastructure comprised 14,648 screening institutions, 273 diagnosis and treatment centers, 865 hearing and speech rehabilitation institutions, and 389 special schools for deaf-mutes. The corresponding Gini coefficients were 0.21, 0.36, 0.29, and 0.26, respectively (Figure 1), indicating relative to adequate equality in resource distribution.

Health Impacts

Screening coverage of Newborn Hearing Screening in China: Initial data collection in 2005 revealed that only nine PLADs reported newborn hearing screening cases, with a coverage rate of 10.9%. Following program implementation and promotion efforts, coverage expanded significantly, with 30 PLADs (excluding Xizang Autonomous Region) reporting data in 2010, achieving 37.8% newborn coverage. This rate subsequently increased substantially to 81.5% by 2015 (Figure 2, Supplementary Table S1, available at https://weekly.chinacdc.cn/).

By 2020, China had achieved a 94.3% initial hearing screening completion rate among newborns. Of those who failed the initial screening, 87.2%

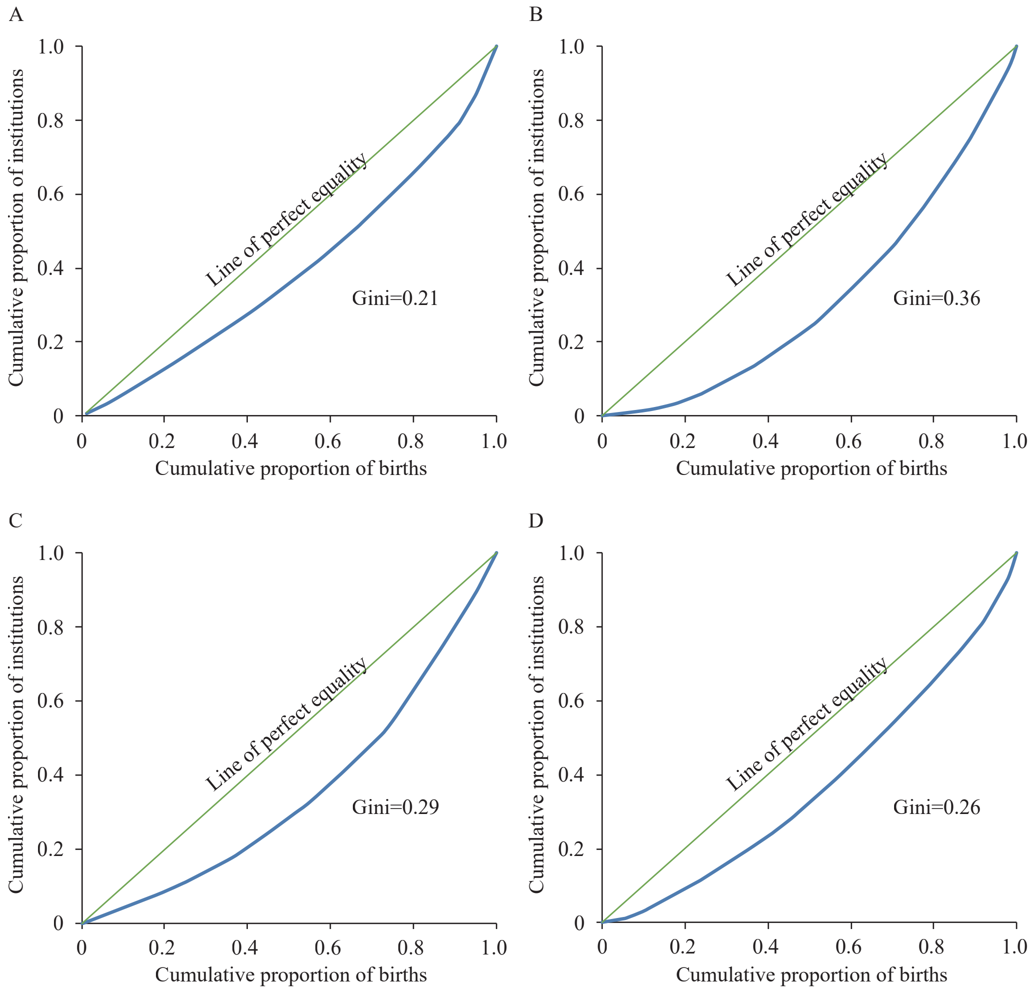

FIGURE 1. Distribution of health services and educational resources in China, 2020. (A) Lorenz curve for hearing screening institutions; (B) Lorenz curve for hearing diagnosis and treatment centers; (C) Lorenz curve for rehabilitation institutions; (D) Lorenz curve for special schools.

Note: The green line represents perfect equality. The deviation between the two curves reflects the magnitude of inequality in resource distribution. The Gini coefficients are 0.21, 0.36, 0.29, and 0.26, respectively.

completed the repeat screening protocol. Among infants who failed the repeat screening, 62.0% received comprehensive audiological diagnosis, resulting in a congenital hearing loss detection rate of 1.6 per 1,000 newborns (Supplementary Table S2, available at https://weekly.chinacdc.cn/).

Special schools for deaf-mutes and hearing-impaired students in special schools: Students with hearing impairments may attend one of three educational settings: regular schools, comprehensive special schools that serve multiple types of disabilities, or specialized schools exclusively for deaf-mutes. In 2001, before the widespread implementation of UNHS, specialized schools for deaf students comprised 41.7% (639/1,531) of all special schools in China. This proportion decreased to 31.7% (541/1,706) by 2010, and further declined to 17.3% (389/2,244) in 2020, six years after achieving national UNHS coverage (Supplementary Figure S3, available at https://weekly.chinacdc.cn/).

Concurrent with this institutional shift, enrollment of hearing-impaired students in special schools has shown a marked decline over the past two decades. From 2001 to 2020, the number of hearing-impaired students in special schools decreased by 54.4%, from 76,554 to 34,945 (Supplementary Figure S3).

Mainstream education proportion among hearing-impaired students: In China, hearing-impaired students who achieve satisfactory rehabilitation outcomes typically integrate into mainstream schools. The mainstream education proportion was calculated as the ratio of hearing-impaired students in mainstream schools to the total number of hearing-impaired students in both mainstream and special schools.

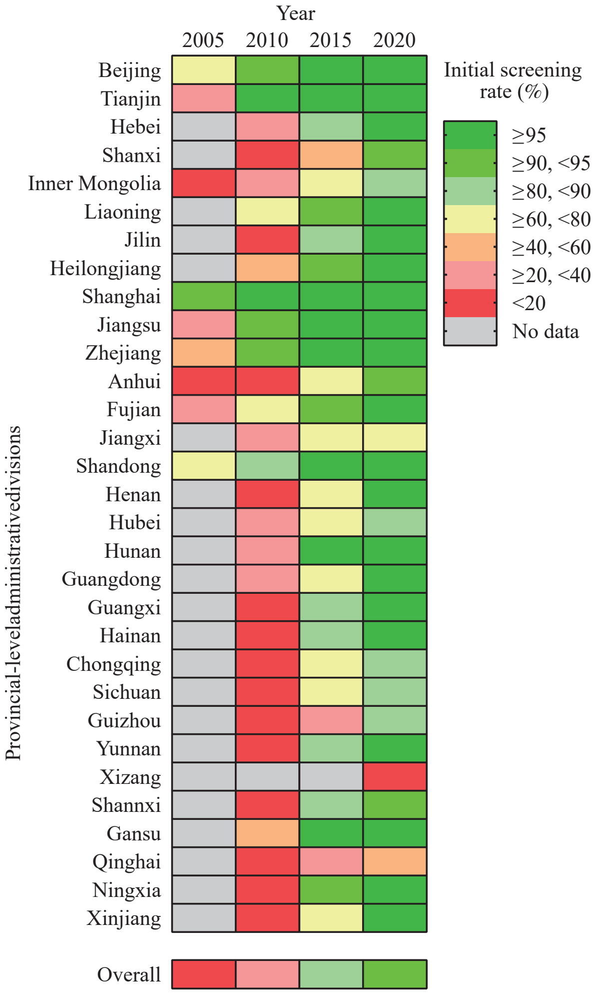

FIGURE 2. Heat map of UNHS coverage across 31 PLADs in China for 2005, 2010, 2015, and 2020.

Note: Overall screening coverage rates for 2005, 2010, 2015, and 2020 were 10.9%, 37.8%, 81.5%, and 94.3%, respectively. The heat map employs a color gradient to represent screening rates across divisions, with green indicating higher coverage and red indicating lower coverage. Gray-shaded areas represent unavailable data.

Abbreviation: UNHS=Universal newborn hearing screening; PLADs=provincial-level administrative divisions.

Students enrolled in attached special education classes within mainstream schools, though relatively few, were excluded from this calculation. The overall mainstream education proportion for hearing-impaired students from grades one through nine increased substantially from 24.8% in 2001 to 57.5% in 2020 (Table 1). When analyzed by educational stage within China's nine-year compulsory education system, which comprises elementary school (grades one through six) and middle school (grades seven through nine), the mainstream education proportion showed differential growth. From 2001 to 2020, elementary school integration increased from 26.8% to 62.2%, while middle school integration rose from 16.5% to 48.2%.

Challenges and Prospects

This nationwide study demonstrates that China's UNHS program coverage increased substantially from 10.9% to 94.3%, while concurrent mainstream school enrollment for hearing-impaired students rose markedly from 24.8% to 57.5% over the past two decades.

The UNHS program, as a proactive public health initiative, has profoundly impacted early diagnosis, etiological identification, and timely intervention for pediatric hearing loss. China's remarkable progress in screening coverage from 10.9% in 2005 to 94.3% in 2020 was facilitated by technical advancements, enhanced training implementation, and particularly the development of the maternal and child health system. The dramatic increase in hospital delivery rates from 76.0% in 2001 to 99.2% in 2012 enabled the integration of newborn screening as standard hospital protocol (*9*). However, significant regional disparities persist, with some PLADs reporting screening rates substantially below the national average. The Gini coefficient for diagnosis and treatment centers (0.36) exceeds those of other resources (0.21, 0.29, and 0.26 for screening institutions, rehabilitation facilities, and special schools, respectively), likely reflecting the higher staffing and equipment requirements for diagnostic facilities. These disparities highlight potential areas for UNHS system improvement. Despite the establishment of a preliminary UNHS management framework, many specialists advocate for developing a nationally integrated informatics platform to enhance screening, diagnosis, and intervention rates while addressing regional inequities.

Historically, hearing-impaired children were predominantly enrolled in specialized schools for the deaf and hard of hearing (*10*). Contemporary approaches now emphasize mainstream education integration, supported by early diagnosis and comprehensive hearing interventions. For instance, in the Netherlands, 61% of hearing-impaired children attend mainstream elementary education (*11*). Modern mainstream schools increasingly provide inclusive educational environments through various formats, including regular classes, resource rooms, and separate classes. In mainland China, the proportion of hearing-impaired students in regular mainstream classes has risen substantially from 24.8% in 2001 to 57.5% in 2020. Within mainstream schools, hearing-impaired

TABLE 1. Number and proportion of hearing-impaired students in mainstream education in China, 2001–2020.

Year	Compulsory Education Stage (grade 1st–9th)		Elementary School Stage (grade 1st–6th)		Middle School Stage (grade 7th–9th)	
	N	Proportion (%)	*N*	Porportion (%)	*N*	Proportion (%)
2001	25,520	24.8	22,327	26.8	3,193	16.5
2002	27,408	25.2	22,308	26.4	5,100	21.1
2003	26,558	24.2	21,353	25.8	5,205	19.3
2004	27,060	24.0	21,122	25.2	5,938	20.4
2005	27,781	24.1	21,733	25.8	6,048	19.6
2006	26,444	22.8	20,620	24.5	5,824	18.4
2007	28,268	24.9	21,111	25.3	7,157	23.7
2008	26,727	23.9	19,427	24.1	7,300	23.5
2009	25,412	23.3	17,865	23.0	7,547	23.9
2010	23,980	22.6	17,189	22.9	6,791	22.1
2011	21,389	21.2	14,866	21.1	6,523	21.6
2012	19,244	20.5	13,674	20.7	5,570	19.9
2013	17,189	20.8	12,334	21.2	4,855	19.7
2014	20,095	24.4	14,469	25.1	5,626	22.8
2015	24,432	29.3	17,784	30.4	6,648	26.6
2016	28,425	33.8	20,846	35.4	7,579	29.9
2017	34,000	40.3	24,959	43.0	9,041	34.3
2018	35,348	44.0	25,576	47.7	9,772	36.6
2019	42,900	51.9	30,907	56.7	11,993	42.6
2020	47,251	57.5	33,853	62.2	13,398	48.2

Note: Source from public data released by the Ministry of Education of China, at http://www.moe.gov.cn/jyb_sjzl/moe_560/.

students are primarily integrated through two approaches: attached special classes (dedicated classes for hearing-impaired students) and full integration into regular classes, with the latter being the predominant model. Future research should focus on tracking the academic performance of hearing-impaired students, given the long-term developmental impact of hearing loss. Additionally, an integrated service system encompassing both medical treatment and education is anticipated.

The reduction in special schools for deaf-mutes from 679 in 2001 to 389 in 2020 can be attributed to several key factors. First, the expanded UNHS coverage and enhanced early intervention protocols have played a crucial role. Second, systematic educational reforms have significantly influenced this transition. Third, the comprehensive service system for hearing-impaired children has evolved to integrate screening, diagnosis, intervention, rehabilitation, and education through coordinated efforts among the Health Commission, the Disabled Persons' Federations, and the Ministry of Education. This multi-departmental collaboration has effectively reduced both the number of specialized schools and their enrollment rates. However, the shift toward mainstream education cannot be solely attributed to increased UNHS coverage, as multiple factors influence this trend, including health and educational policies, financial support mechanisms, and broader socioeconomic considerations. For example, more than 10 PLADs (including Shanghai, Jiangsu, Zhejiang, etc.) have progressively included cochlear implants in their basic medical insurance coverage. Furthermore, the first centralized procurement program will significantly reduce cochlear implant costs from over 200,000 CNY (27,400 USD) to approximately 50,000 CNY after March 2025, substantially improving intervention accessibility for hearing-impaired newborns. Additionally, as part of the educational reform, many special schools for deaf-mutes are transitioning into rehabilitation schools for preschool children with hearing aids and/or cochlear implants, focusing on preparing them for future mainstream society integration. Consequently, many teachers of the deaf are undergoing specialized training to become speech and language therapists (SLTs).

Over the past two decades, China has achieved remarkable progress in expanding newborn hearing screening coverage and increasing mainstream school enrollment among hearing-impaired students. To address persistent challenges, including regional disparities in screening and diagnostic rates, the establishment of a comprehensive national informatic platform for the UNHS system remains essential.

Conflicts of interest: No conflicts of interest.

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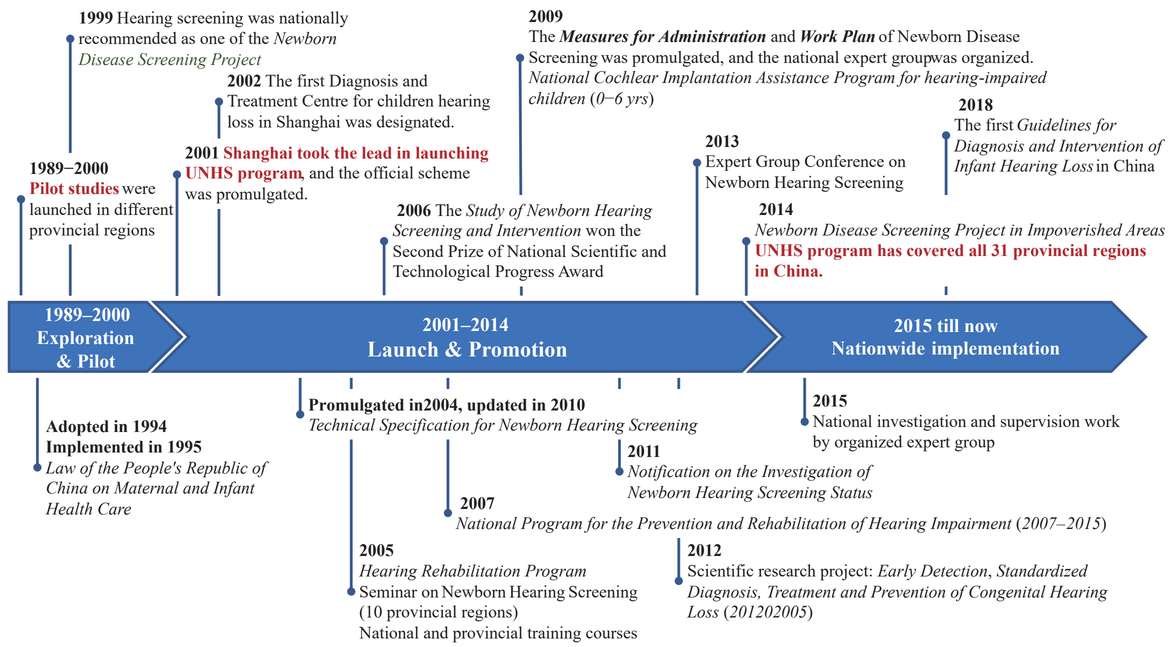
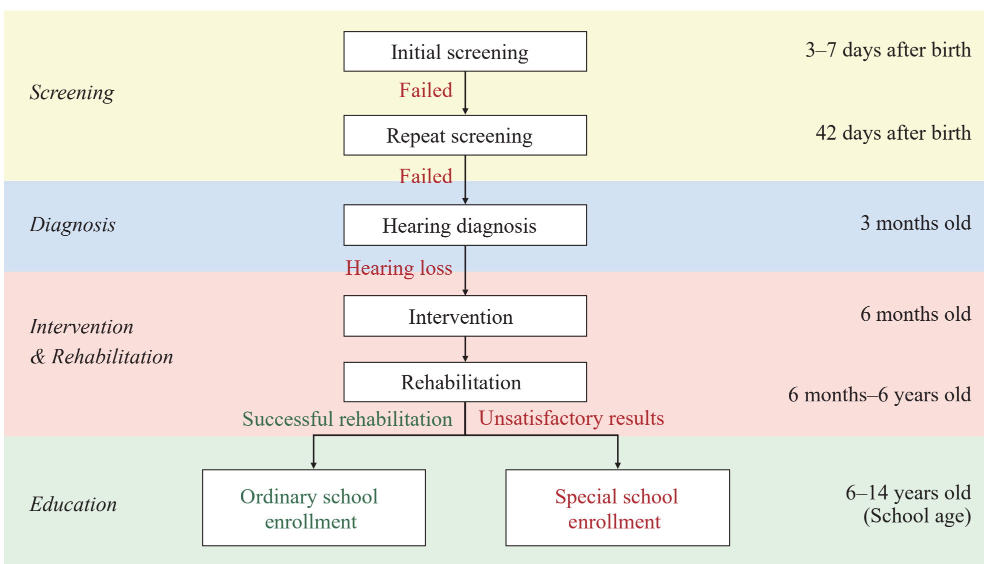
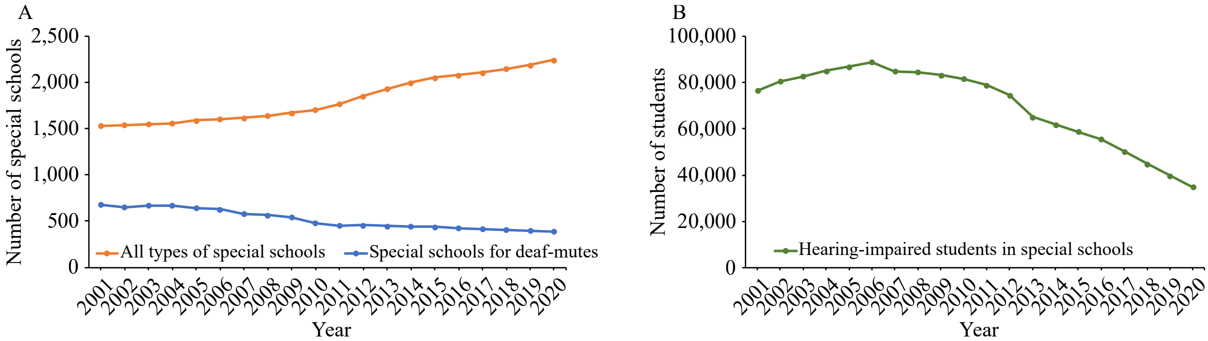
SUPPLEMENTARY MATERIALS



SUPPLEMENTARY FIGURE S1. History of UNHS program in China.
Note: The launch of the UNHS program in Shanghai in 2001 marked the beginning of the launch and promotion stage. The nationwide coverage of the UNHS program in 2014 marked the beginning of the nationwide implementation stage.
Abbreviation: UNHS=Universal newborn hearing screening.



SUPPLEMENTARY FIGURE S2. The current Process of UNHS in mainland China.
Note: The process comprises four sequential phases: Screening, Diagnosis, Intervention and Rehabilitation, and Education, with corresponding age ranges indicated.
Abbreviation: UNHS=Universal newborn hearing screening.



SUPPLEMENTARY FIGURE S3. Trends of special schools and hearing-impaired students in mainland China from 2001 to 2020. (A) Number of all special schools and special schools for deaf-mutes; (B) Number of hearing-impaired students in special schools.

SUPPLEMENTARY TABLE S1. Initial screening, repeat screening, and diagnosis data in 31 provincial regions of China in 2020.

PLADs	Number of live births	Initial screening			Repeated screening			Diagnosis			Detection rate (‰)
		Involved cases		Referral cases	Involved cases		Referral cases	Involved cases		Confirmed cases	
		Number	Rate (%)		Number	Rate (%)		Number	Rate (%)		
Beijing	161,222	157,866	97.9	8,982	7,900	88.0	1,254	1,140	90.9	435	2.8
Tianjin	77,295	77,079	99.7	6,296	5,459	86.7	551	370	67.2	226	2.9
Hebei	586,662	560,457	95.5	52,138	36,486	70.0	3,678	2,659	72.3	316	0.6
Shanxi	259,983	239,219	92.0	26,326	10,710	40.7	1,478	395	26.7	147	0.6
Inner Mongolia	122,053	106,016	86.9	7,719	5,944	77.0	714	73	10.2	50	0.5
Liaoning	212,878	209,484	98.4	14,104	11,261	79.8	1,790	N/A	N/A	118	0.6
Jilin	111,660	110,401	98.9	10,644	7,951	74.7	962	877	91.2	370	3.4
Heilongjiang	116,457	114,094	98.0	6,721	4,440	66.1	681	616	90.5	133	1.2
Shanghai	136,388	133,633	98.0	N/A	N/A	N/A	1,279	1,117	87.3	249	1.9
Jiangsu	550,388	547,718	99.5	33,683	29,690	88.1	4,272	2,876	67.3	737	1.3
Zhejiang	476,657	474,730	99.6	35,605	34,561	97.1	5,268	5,157	97.9	1,099	2.3
Anhui	516,815	486,268	94.1	43,882	36,940	84.2	4,658	1,447	31.1	357	0.7
Fujian	380,098	368,062	96.8	30,926	26,979	87.2	5,362	N/A	N/A	571	1.6
Jiangxi	617,889	494,026	80.0	54,363	50,968	93.8	10,448	9,510	91.0	1,345	2.7
Shandong	864,894	856,997	99.1	64,035	80,821	126.2	7,894	7,995	101.3	1,743	2.0
Henan	991,175	960,977	97.0	80,149	62,909	78.5	10,760	1,882	17.5	841	0.9
Hubei	437,947	392,620	89.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hunan	566,400	541,536	95.6	49,567	47,211	95.2	6,759	5,400	79.9	2,134	3.9
Guangdong	1,431,585	1,389,698	97.1	71,080	N/A	N/A	N/A	6,758	N/A	1,476	1.1
Guangxi	575,303	571,536	99.3	49,255	40,229	81.7	11,908	4,543	38.2	2,447	4.3
Hainan	109,585	108,533	99.0	7,973	5,165	64.8	1,410	668	47.4	265	2.4
Chongqing	220,545	190,573	86.4	6,345	4,977	78.4	374	172	46.0	97	0.5
Sichuan	655,856	589,510	89.9	43,271	33,308	77.0	5,455	3,198	58.6	1,153	2.0
Guizhou	526,062	458,179	87.1	27,321	19,945	73.0	1,054	948	89.9	175	0.4
Yunnan	513,636	494,982	96.4	38,904	32,463	83.4	2,716	1,229	45.3	364	0.7
Xizang	54,288	5,095	9.4	174	208	119.5	6	N/A	N/A	N/A	N/A
Shannxi	360,062	339,657	94.3	30,753	25,172	81.9	2,662	2,360	88.7	168	0.5
Gansu	256,672	252,898	98.5	45,595	51,271	112.4	3,389	1,186	35.0	101	0.4
Qinghai	68,803	33,040	48.0	3,231	1,865	57.7	874	267	30.5	47	1.4
Ningxia	80,265	79,305	98.8	5,000	3,463	69.3	420	395	94.0	78	1.0
Xinjiang	185,495	180,576	97.3	13,531	15,945	117.8	1,552	827	53.3	35	0.2
Total	12,225,018	11,524,765	94.3	867,573	694,241	87.2	99,628	64,065	62.0	17,277	1.6

Note: In some of the provincial regions, the repeated screening rate or diagnosis rate were beyond 100%, mainly because of the interprovincial population mobility and the lack of a uniform UNHS information system between each provincial region. Total repeated screening rate = Total number of cases involved in repeated screening ÷ Total number of referral cases in initial screening. In this calculation, Guangdong, Hubei, and Sichuan were excluded because of the lack of data in repeated screening. Total diagnosis rate = Total number of cases involved in diagnosis ÷ Total number of referral cases in repeated screening. In this calculation, Fujian, Guangdong, Hubei, Liaoning and Xizang PLADs were excluded because of the lack of data in repeated screening or diagnosis. Total detection rate = Total number of confirmed cases ÷ Total number of involve cases in initial screening. In this calculation, Hubei and Xizang were excluded because of the lack of data in diagnosis.

Abbreviation: PLADs=provincial-level administrative divisions; N/A=means data not available.

SUPPLEMENTARY TABLE S2. UNHS coverage in 31 provincial regions of China in 2005, 2010, 2015, and 2020.

Provincial regions	2005			2010			2015			2020		
	Live births	Cases involved in UNHS	Coverage rate (%)	Live births	Cases involved in UNHS	Coverage rate (%)	Live births	Cases involved in UNHS	Initial screening rate (%)	Live births	Cases involved in UNHS	Initial screening rate (%)
Beijing	119,176	78,040	65.5	173,801	159,888	92.0	209,455	202,999	96.9	161,222	157,866	97.9
Tianjin	74,763	26,697	35.7	108,920	106,843	98.1	99,883	99,222	99.3	77,295	77,079	99.7
Hebei	876,972	N/A	N/A	753,010	297,669	39.5	1,112,760	893,700	80.3	586,662	560,457	95.5
Shanxi	63,533	N/A	N/A	98,911	7,970	8.1	231,581	121,299	52.4	259,983	239,219	92.0
Inner Mongolia	66,941	2,165	3.2	80,210	26,957	33.6	115092	73,211	63.6	122,053	106,016	86.9
Liaoning	295,752	N/A	N/A	308,010	237,100	77.0	295,469	273,652	92.6	212,878	209,484	98.4
Jilin	214,016	N/A	N/A	217,011	18,534	8.5	167,481	150,337	89.8	111,660	110,401	98.9
Heilongjiang	244,722	N/A	N/A	247,057	126,033	51.0	179,247	167,079	93.2	116,457	114,094	98.0
Shanghai	125,130	114,512	91.5	194,942	186,799	95.8	191,290	188,164	98.4	136,388	133,633	98.0
Jiangsu	688,400	179,754	26.1	767,233	695,190	90.6	840,604	826,743	98.4	550,388	547,718	99.5
Zhejiang	535,442	233,182	43.5	616,417	575,819	93.4	657,157	651,885	99.2	476,657	474,730	99.6
Anhui	577,686	3,205	0.6	693,728	85,922	12.4	697,955	553,335	79.3	516,815	486,268	94.1
Fujian	408,668	96,653	23.7	404,278	311,205	77.0	609,017	571,248	93.8	380,098	368,062	96.8
Jiangxi	466,061	N/A	N/A	596,270	124,081	20.8	628,241	447,773	71.3	617,889	494,026	80.0
Shandong	907,681	688,343	75.8	1,110,000	958,609	86.4	1,255,589	1,210,796	96.4	864,894	856,997	99.1
Henan	1,120,000	N/A	N/A	1,170,000	99,927	8.5	1,360,000	1,033,262	76.0	991,175	960,977	97.0
Hubei	512,426	N/A	N/A	587,292	195,738	33.3	614,172	434,011	70.7	437,947	392,620	89.7
Hunan	774,928	N/A	N/A	797,902	303,611	38.1	791,036	771,179	97.5	566,400	541,536	95.6
Guangdong	1,023,633	N/A	N/A	1,694,939	600,968	35.5	1,810,422	1,400,969	77.4	1,431,585	1,389,698	97.1
Guangxi	680,844	N/A	N/A	720,000	61,494	8.5	827,135	732,970	88.6	575,303	571,536	99.3
Hainan	120,570	N/A	N/A	127,434	2,138	1.7	137,082	119,799	87.4	109,585	108,533	99.0
Chongqing	278,240	N/A	N/A	263,362	32,619	12.4	306,455	207,899	67.8	220,545	190,573	86.4
Sichuan	821,445	N/A	N/A	724,670	89,754	12.4	787,068	490,871	62.4	655,856	589,510	89.9
Guizhou	170,992	N/A	N/A	393,137	7,819	2.0	394,561	142,308	36.1	526,062	458,179	87.1
Yunnan	652,464	N/A	N/A	600,832	10,081	1.7	524,252	428,799	81.8	513,636	494,982	96.4
Xizang	32,554	N/A	N/A	42,338	N/A	N/A	53,506	N/A	N/A	54,288	5,095	9.4
Shannxi	371,993	N/A	N/A	363,000	44,959	12.4	447,610	383,967	85.8	360,062	339,657	94.3
Gansu	328,158	N/A	N/A	282,873	125,827	44.5	278,642	276,039	99.1	256,672	252,898	98.5
Qinghai	84,937	N/A	N/A	83,664	1,404	1.7	62,601	13,459	21.5	68,803	33,040	48.0
Ningxia	94,306	N/A	N/A	77,450	6,989	9.0	94,482	88,511	93.7	80,265	79,305	98.8
Xinjiang	326,183	N/A	N/A	347,303	29,662	8.5	456,584	281,459	61.6	185,495	180,576	97.3
Total*	13,058,616	1,422,551	10.9	14,645,994	5,531,609	37.8	16,236,429	13,236,945	81.5	12,225,018	11,524,765	94.3

Abbreviation: UNHS =Universal newborn hearing screening.

* Total coverage rate = Total cases involved in UNHS ÷ Total live births. N/A means data not available.

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