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Physical Fitness and Risk of Mental Disorders in Children and Adolescents

Huey-Ling Chiang, MD, PhD; Yi-Fang Chuang, MD, PhD; Yi-An Chen, BPH; Chen-Te Hsu, PhD;
Chien-Chang Ho, PhD; Hsiu-Tao Hsu, MSc; Yi-Han Sheu, MD, MPH, ScD; Susan Shur-Fen Gau, MD, PhD;
Li-Lin Liang, PhD

IMPORTANCE With the rising prevalence of mental disorders among children and adolescents, identifying modifiable associations is critical.

OBJECTIVE To examine the association between physical fitness and mental disorder risks.

DESIGN, SETTING, AND PARTICIPANTS This nationwide cohort study used data from the Taiwan National Student Fitness Tests and National Health Insurance Research Databases from January 1, 2009 to December 31, 2019. Participants were divided into 2 cohorts targeting anxiety and depression (1 996 633 participants) and attention-deficit/hyperactivity disorder (ADHD; 1 920 596 participants). Participants were aged 10 to 11 years at study entry and followed up for at least 3 years, had a nearly equal gender distribution, and an average follow-up of 6 years. Data were analyzed from October 2022 to February 2024.

EXPOSURES Assessments of physical fitness included cardiorespiratory fitness (CF), muscular endurance (ME), muscular power (MP), and flexibility, measured through an 800-m run time, bent-leg curl-ups, standing broad jump, and sit-and-reach test, respectively.

MAIN OUTCOMES AND MEASURES Kaplan-Meier method calculated the cumulative incidence of anxiety, depression, and ADHD across fitness quartiles. Additionally, multivariable Cox proportional hazards models were used that included all 4 fitness components and explored sex and income as modifiers.

RESULTS The anxiety and depression cohort had 1 996 633 participants (1 035 411 participants were male [51.9%], and the median [IQR] age was 10.6 [10.3-11.0] years), while the ADHD cohort had 1 920 596 (975 568 participants were male [51.9%], and the median [IQR] age was 10.6 [10.3-11.0] years). Cumulative incidence of mental disorders was lower among participants in better-performing fitness quartiles, suggesting a dose-dependent association. Gender-specific analyses, controlling for confounders, revealed that improved CF, indicated by a 30-second decrease in run times, was associated with reduced risks of anxiety, depression, and ADHD in female participants, and lower risks of anxiety and ADHD in male participants (adjusted hazard ratio [aHR] for ADHD risk for female participants, 0.92; 95% CI, 0.90-0.94; $P < .001$; for male participants, 0.93; 95% CI, 0.92-0.94; $P < .001$). Enhanced ME, marked by an increase of 5 curl-ups per minute, was associated with decreased risks of depression and ADHD in female participants, and lower anxiety and ADHD risks in male participants (aHR for ADHD risk for female participants, 0.94; 95% CI, 0.92-0.97; $P < .001$; for male participants, 0.96; 95% CI, 0.95-0.97; $P < .001$). Improved MP, reflected by a 20-cm increase in jump distance, was associated with reduced risks of anxiety and ADHD in female participants and reduced anxiety, depression, and ADHD in male participants (aHR for ADHD risk for female participants, 0.95; 95% CI, 0.91-1.00; $P = .04$; for male participants, 0.96; 95% CI, 0.94-0.99; $P = .001$).

CONCLUSIONS AND RELEVANCE This study highlights the potential protective role of cardiorespiratory fitness, muscular endurance, and muscular power in preventing the onset of mental disorders. It warrants further investigation of the effectiveness of physical fitness programs as a preventive measure for mental disorders among children and adolescents.

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Supplemental content

Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Authors: Li-Lin Liang, PhD, Institute of Public Health, College of Medicine, National Yang Ming Chiao Tung University, No. 155 Linong St, Section 2, Beitou District, Taipei 11221, Taiwan (liang.lilin@nycu.edu.tw); Susan Shur-Fen Gau, MD, PhD, Department of Psychiatry, National Taiwan University Hospital and College of Medicine, No. 7 Chung-Shan S Rd, Taipei 10002, Taiwan (gaushufe@ntu.edu.tw).

The World Health Organization reported 1 in 7 individuals aged 10 to 19 years are affected by mental health problems, the leading cause of health-related disability in this age group worldwide.[1,2] The increasing prevalence of mental disorders has highlighted the urgent need to enhance mental health,[3,4] emphasizing the identification of protective factors against these challenges.

Physical fitness is a measurable physiological characteristic indicative of an individual's ability to carry out physical tasks. It is largely driven by genetic factors in school-age children and adolescents,[5] yet can also be improved through adequate physical activity interventions.[6] The literature about the importance of physical activity for mental health by improving neuropsychological functioning and well-being, as well as decreasing and preventing conditions such as anxiety and depression has been rapidly evolving over the past few decades.[6,7] In addition, evidence from randomized clinical trials indicates that improvements in physical fitness may mediate the health benefits derived from physical activity interventions.[8,9] Taken together, this implies that physical fitness may play a significant role in the mental well-being of children and adolescents.

Previous research indicates a positive link between physical fitness and mental health in children and adolescents.[10-12] For example, lower cardiorespiratory fitness is often linked to increased depression[13-15] and overall psychological difficulties,[16] while results for muscular fitness varied.[15-17] However, these are cross-sectional studies and are, therefore, vulnerable to reverse causation. In addition, these studies rely heavily on questionnaires instead of clinical diagnosis for outcome measurement, compromising precision. Only 1 study showed that lower childhood cardiorespiratory fitness is associated with increased attention-deficit/hyperactivity disorder (ADHD) symptoms in adolescence, even after adjusting for baseline ADHD symptoms.[12] Another study demonstrated that lower muscular fitness was associated with increased ADHD symptoms in young adults.[18] However, these findings are only based on teachers' reports[12] or self-report.[18] Since ADHD diagnosis[19] requires symptoms in multiple settings to avoid false positives, a comprehensive psychiatric diagnosis is necessary to establish a better understanding of the relationship between physical fitness and ADHD. In summary, despite a plausible link, existing studies often face significant limitations in their design and demonstrate inconsistent correlational patterns between various fitness components and mental health outcomes. Consequently, the current evidence on the role of physical fitness in mental disorders among children and adolescents remains inconclusive. This may be attributable to the scarcity of available data, which limits the scope and design of studies that can be pursued.

In a study conducted from 2015 to 2017 on Taiwanese children aged 7 to 15 years, the most common mental disorders identified were anxiety disorders and ADHD, with 6-month prevalence rates of 12% and 8.7%, respectively.[4] The prevalence of depressive disorders and ADHD increased compared with previous research in Taiwan,[20] while the prevalence of anxiety disorders remained comparable.[4,20] On the other hand, there has been a continuing decreasing trend in physical fitness among Taiwanese children and adolescents over the past 2 decades,[21] a trend similarly observed in developed countries.[22] Hence, there is a keen need to explore whether physical fitness is associated with mental disorders and can serve as an important indicator for identifying individuals at risk of developing mental disorders. Therefore, we assume that physical fitness may play an essential role in the mental health of children and adolescents, but its significance is underestimated due to a relative lack of relevant longitudinal studies. Our study aims to examine the association between physical fitness and long-term mental disorder risks, including depression, anxiety, and ADHD, in children and adolescents. Using a longitudinal approach with a large national cohort, we investigated the association between different physical fitness components and the incidence of these mental disorders.

Key Points

Question Is physical fitness associated with long-term risks of mental disorders in children and adolescents?

Findings This nationwide cohort study, encompassing 1.9 million participants in Taiwan, revealed that children and adolescents in better-performing fitness quantiles exhibited lower cumulative incidences of anxiety disorders, depressive disorders, and attention-deficit/hyperactivity disorder. Notably, enhanced cardiorespiratory fitness, muscular endurance, and muscular power were independently associated with reduced mental disorder incidences in this demographic, even after accounting for confounding factors.

Meaning These findings suggest the potential of cardiorespiratory and muscular fitness as protective factors in mitigating the onset of mental disorders among children and adolescents.

Methods

Data Sources

The study used nationwide retrospective data from the National Health Insurance Research Database (NHIRD) and the National Student Fitness Tests Database (NSFTD) in Taiwan. The NHIRD contains comprehensive medical claims data, covering demographics, health care services utilization, diagnostics, prescriptions, and records of tests and medical procedures.[23,24] NHIRD collaborates with 94% of medical institutions nationwide.[25] The NSFTD, managed by the Sports Administration, Ministry of Education, compiles nationwide data from annual physical fitness assessments and body mass index (BMI) of students. This extensive data set, collected from 2009 to 2018 across educational institutions in Taiwan, includes records of around 2 million students yearly, totaling 4.55 million unique entries over the decade (detailed in eMethods 1 in Supplement 1). The ethics review boards of Far Eastern Memorial Hospital, National Yang Ming Chiao Tung University and Yuan's General Hospital in Taiwan approved study procedures and exempted informed consent because all data were deidentified and retrieved anonymously. This investigation followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Study Design and Population

To explore the association between physical fitness and mental disorders, we constructed 2 distinct cohorts: anxiety and depression (ANX-DEP) and ADHD. The observational window spanned from January 1, 2009, to December 31, 2019. Eligible participants were students aged 10 or 11 years and with a minimum follow-up of 3 years, ending on December 31, 2019. We established a minimum 3-year follow-up to ensure that the observation period for participants aged 10 and 11 years at study entry was adequately long to capture the development of mental disorders.

The study excluded individuals with prior cerebral palsy diagnosis. For the ANX-DEP and ADHD cohorts, individuals who had previously been diagnosed with ANX-DEP and ADHD, respectively, were also excluded. Anxiety disorders were identified using *International Classification of Diseases, Ninth Revision (ICD-9)* codes 300.00, 300.01, 300.02, 300.09, and *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10)* code F41. Depressive disorders were identified using *ICD-9* codes 296.2, 296.3, and 296.82, and *ICD-10* codes F32 and F33. ADHD was ascertained via *ICD-9* code 314 and *ICD-10* code F90. These exclusion criteria were determined by the absence of diagnosis codes for the respective disorders in outpatient data since January 1, 2008, and inpatient data from January 1, 2000, until the day before the index date. The index date, marking the start of follow-up, was established as the 366th day after the physical fitness test, introducing a 1-year lag between the physical fitness test and the start of follow-up. This 1-year washout period guarantees that diagnoses and any associated medication prescriptions for mental disorders occur at least 1 year after the physical fitness assessments, thereby reducing the possibility of reverse causation. Additional exclusions were applied to individuals who had passed away before the index date, as well as those with missing or implausible BMI data or lacking data for any of the 4 physical fitness components at the entry age.

Physical Fitness Measures

The fitness assessment includes 4 components: an 800-m run (cardiorespiratory fitness [CF]), bent-leg curl-ups in 1 minute (muscular endurance [ME]), a standing broad jump (muscular power [MP]), and the distance attained in the 2-leg sit-and-reach test (flexibility fitness [FF]). Better fitness is shown by a faster run time (lower score in CF) or higher scores in ME, MP, and FF. The scores from these 4 physical fitness components, recorded at the age of 10 or 11 years, serve as the primary association with the subsequent risk of mental disorders.

Main Outcome Measures

The primary outcome was the onset of a mental disorder after the index date, characterized as either anxiety or depression in the ANX-DEP cohort, and ADHD in the ADHD cohort. Diagnoses of these disorders were based on clinical interviews conducted with parents and children by clinicians. These assessments also incorporated observations or evaluations by school teachers, adhering to the *Diagnostic and Statistical Manual of Mental Disorders* (Fourth Edition) or *ICD-10* criteria. Clinicians made all diagnoses, with 90% of anxiety disorders, 97% of depressive disorders, and 93% of ADHD diagnoses being first identified by board-certified psychiatrists. A diagnosis was established through at least 3 outpatient visits or a single inpatient admission with relevant diagnostic codes during the follow-up period,[26] as outlined in the study design. The onset of each mental disorder was determined by the earliest recorded diagnosis date. Diagnostic accuracy is further supported by claims data, indicating that 75% to 84% of outpatient visits for mental disorders within the first year following the initial diagnosis involved medication prescription. For more details, please see eMethods 2 in Supplement 1.

Other Covariates

To account for potential confounding effects, we adjusted for several variables, including age at assessment, BMI[12] comorbidities, urbanization level,[27] and birth years. Age- and sex-specific BMI was categorized based on Taiwan's Ministry of Education guidelines on underweight, average, overweight, or obese.[28]

In the ANX-DEP and ADHD cohorts, we considered specific comorbidities, including intellectual disabilities, autism spectrum disorder, and developmental disorders, diagnosed both before and after the index date. This approach recognized the potential for diagnoses to be made belatedly.

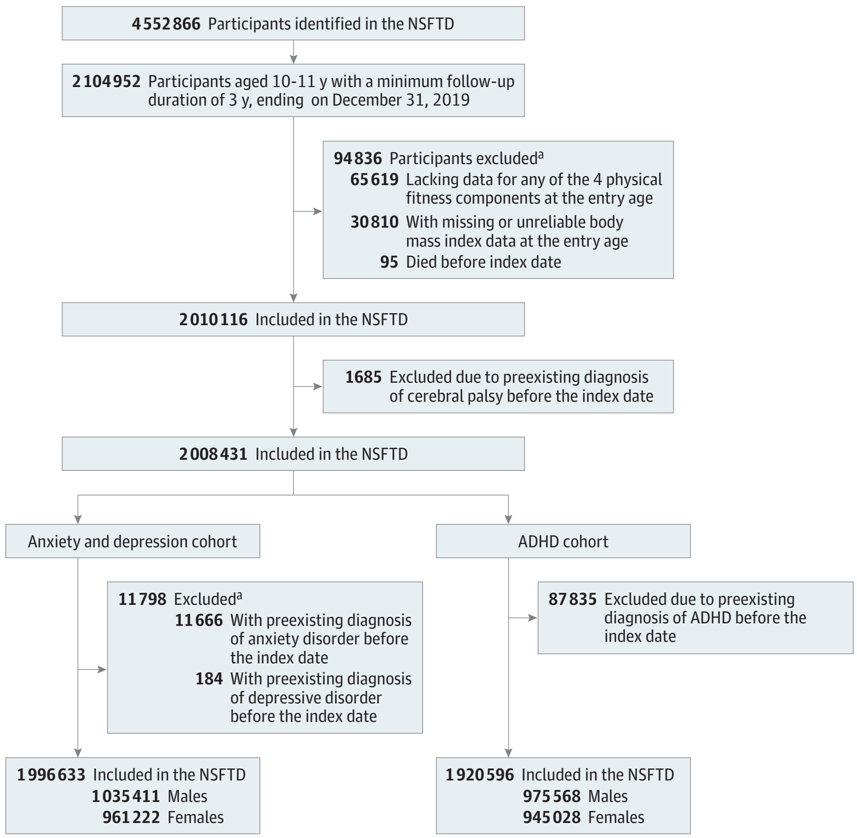
We used Taiwan's Ministry of the Interior's scheme to evaluate urbanization, categorizing 368 townships into 5 levels from urban (level 1) to rural (level 5).[29] This classification comes from a comprehensive analysis incorporating population density, the presence of industrial activities, and transportation infrastructure.

Due to the inclusion of children and adolescents from different birth cohorts in our data, we incorporated birth years into our analysis to address potential variations in diagnostic practices and awareness of mental disorders across these cohorts. For details on data processing and variable coding, please see eMethods 3 in Supplement 1.

Statistical Analysis

To ensure a clear temporal association between physical fitness and the onset of mental disorders, we implemented a 1-year lag after the physical fitness test. Students were then followed up until the first diagnosis of anxiety or depression (ANX-DEP cohort) or ADHD (ADHD cohort), death, or until December 31, 2019. Separate analyses for male and female students were conducted to account for sex-specific differences in the association between physical fitness and mental disorders. This method was chosen after finding that sex is a potential effect modifier, indicated by interaction term analysis. The Kaplan-Meier method calculated cumulative incidences of mental disorders across physical fitness quartiles, with Gray test comparing the equality of these cumulative incidence curves between groups.[30]

Figure 1. Study Flow Diagram



Two distinct cohorts were constructed: anxiety and depression (1 996 633 participants) and attention-deficit/hyperactivity disorder (ADHD; 1 920 596 participants). ADHD indicates attention-deficit/hyperactivity disorder; NSFTD, National Student Fitness Tests Database.

[a]A participant could meet multiple exclusion criteria.

To assess if physical fitness is independently associated with mental disorder risks, we used multivariable Cox proportional hazards models, incorporating all 4 physical fitness components. A series of sensitivity analyses were conducted to ensure the robustness of our results. All models adjusted for previously mentioned covariates. χ^2 tests were used to calculate P values. All tests were 2-sided, using a significance level of .05. Statistical analyses were performed using SAS version 14.3 (SAS Institute). Data were analyzed from October 2022 to February 2024.

Results

Demographic Characteristics of Participants

Figure 1 illustrates the study flow for the ANX-DEP and ADHD cohorts. The ANX-DEP cohort had 1 996 633 participants (1 035 411 participants were male [51.9%], and the median [IQR] age was 10.6 [10.3-11.0] years), while the ADHD cohort had 1 920 596 (975 568 participants were male [51.9%], and the median [IQR] age was 10.6 [10.3-11.0] years). Notably, 1 918 640 participants were common to both cohorts.

Table 1 shows that in the ANX-DEP cohort, both female and male students had a mean (SD) follow-up period of 6.0 years (2.4). Fitness tests revealed that female and male participants achieved a mean (SD) of 5.1 (1.0) minutes and 4.9 (1.1) minutes in CF, 26.5 (9.3) curl-ups and 27.9 (10.1) curl-ups in ME, 1.4 (0.2) meters and 1.5 (0.2) meters in MP, and 30.0 (8.5) centimeters and 25.1 (8.2) centimeters in FF. The ADHD cohort had similar characteristics to the ANX-DEP cohort.

Detailed participant characteristics, stratified by CF, ME, MP, and FF quartiles, are provided in eTable 1, eTable 2, eTable 3, and eTable 4 in Supplement 1 for female participants and eTable 5, eTable 6, eTable 7, and eTable 8 for male participants (Supplement 1). Additionally, characteristics of participants for each year within the observation period are detailed in eTable 9 in Supplement 1 for the ANX-DEP cohort and eTable 10 in Supplement 1 for the ADHD cohort.

Cumulative Incidence of Mental Disorders Stratified by Physical Fitness Quartiles

Figure 2 illustrates the cumulative incidence of first-onset ADHD among female participants, whereas **Figure 3** provides analogous data for male participants. Due to space constraints, the cumulative incidence of anxiety disorders for female and male participants are provided in eFigure 1 and eFigure 2 in Supplement 1, respectively. Additionally, the cumulative incidence of depressive disorders for female and male participants are detailed in eFigure 3 and eFigure 4 in Supplement 1, respectively. These figures demonstrate the proportion of the total at-risk population that develops these specific mental disorders for the first time. Gray test revealed significant variations in the cumulative incidence across the fitness quartiles for all 3 disorders (χ^2_3 = 32.62; *P* < .001). The

Table 1. Participant Demographic Characteristics by Sex

Characteristics	Participants, No. (%)	
	Female	Male
Anxiety and depression cohort		
Total No.	961 222	1 035 411
Age, mean (SD) y; median (IQR)	10.7 (0.5); 10.6 (10.3-11.0)	10.7 (0.5); 10.6 (10.3-11.0)
Follow-up year, mean (SD); median (IQR)		
Anxiety disorder	6.0 (2.4); 6.2 (3.8-8.2)	6.0 (2.4); 6.2 (3.8-8.2)
Depressive disorder	6.0 (2.4); 6.2 (3.8-8.2)	6.0 (2.4); 6.2 (3.8-8.2)
Anxiety and depressive disorders[a]	6.0 (2.4); 6.2 (3.8-8.2)	5.9 (2.4); 6.2 (3.8-8.2)
Physical fitness test, mean (SD); median (IQR)		
Cardiorespiratory fitness, min	5.1 (1.0); 5.0 (4.5-5.6)	4.9 (1.1); 4.8 (4.2-5.5)
Muscular endurance, curl-ups	26.5 (9.3); 26.0 (21.0-32.0)	27.9 (10.1); 28.0 (21.0-34.0)
Muscular power, m	1.4 (0.2); 1.4 (1.2-1.5)	1.5 (0.2); 1.5 (1.3-1.6)
Flexibility fitness, cm	30.0 (8.5); 30.0 (25.0-35.0)	25.1 (8.2); 25.0 (20.0-30.0)
Body mass index grade[b]		
Underweight	64 492 (6.7)	53 216 (5.1)
Normal weight	626 209 (65.2)	596 046 (57.6)
Overweight	134 818 (14.0)	176 969 (17.1)
Obesity	135 703 (14.1)	209 180 (20.2)
Comorbid conditions		
Intellectual disabilities	5475 (0.6)	9279 (0.9)
Developmental disorders	17 007 (1.8)	40 886 (4.0)
Autism spectrum disorders	1289 (0.1)	7842 (0.8)
Urbanization[c]		
1 (Urban)	450 083 (46.8)	485 386 (46.9)
2	201 869 (21.0)	217 333 (21.0)
3	122 108 (12.7)	131 026 (12.7)
4	158 246 (16.5)	170 511 (16.5)
5 (Rural)	28 916 (3.0)	31 155 (3.0)
Birth year		
1997-1998	96 265 (10.0)	102 307 (9.9)
1999	118 817 (12.4)	127 761 (12.3)
2000	131 593 (13.7)	141 975 (13.7)
2001	113 547 (11.8)	121 244 (11.7)
2002	109 376 (11.4)	118 495 (11.4)
2003	101 089 (10.5)	109 757 (10.6)
2004	96 440 (10.0)	104 875 (10.1)
2005	92 222 (9.6)	98 945 (9.6)
2006-2007	101 873 (10.6)	110 052 (10.6)
ADHD cohort		
Total No.	945 028	975 568
Age, mean (SD) y; median (IQR)	10.7 (0.5); 10.6 (10.3-11.0)	10.7 (0.5); 10.6 (10.3-11.0)
Follow-up year, mean (SD); median (IQR)	6.0 (2.4); 6.2 (3.8-8.2)	6.0 (2.4); 6.2 (3.8-8.2)
Physical fitness test, mean (SD); median (IQR)		
Cardiorespiratory fitness, min	5.1 (0.9); 5.0 (4.4-5.6)	4.9 (1.1); 4.8 (4.2-5.5)
Muscular endurance, curl-ups	26.5 (9.3); 27.0 (21.0-32.0)	28.0 (10.0); 28.0 (21.0-35.0)
Muscular power, meters	1.4 (0.2); 1.4 (1.2-1.5)	1.5 (0.2); 1.5 (1.3-1.6)
Flexibility fitness, centimeters	30.0 (8.5); 30.0 (25.0-35.0)	25.2 (8.2); 25.0 (20.0-30.0)
Body mass index grade[b]		
Underweight	63 235 (6.7)	49 536 (5.1)
Normal weight	615 631 (65.1)	560 122 (57.4)
Overweight	132 648 (14.0)	167 089 (17.1)
Obesity	133 514 (14.1)	198 821 (20.4)

(continued)

Table 1. Participant Demographic Characteristics by Sex (continued)

Characteristics	Participants, No. (%)	
	Female	Male
Comorbid conditions		
Intellectual disabilities	3570 (0.4)	4672 (0.5)
Developmental disorders	11 362 (1.2)	22 356 (2.3)
Autism spectrum disorders	761 (0.1)	3795 (0.4)
Urbanization[c]		
1 (Urban)	440 009 (46.6)	450 395 (46.2)
2	199 172 (21.1)	206 683 (21.2)
3	120 803 (12.8)	125 600 (12.9)
4	156 373 (16.6)	162 808 (16.7)
5 (Rural)	28 671 (3.0)	30 082 (3.1)
Birth year		
1997-1998	95 728 (10.1)	99 864 (10.2)
1999	117 879 (12.5)	123 708 (12.7)
2000	130 155 (13.8)	136 128 (14.0)
2001	111 872 (11.8)	114 731 (11.8)
2002	107 427 (11.4)	111 047 (11.4)
2003	98 968 (10.5)	101 962 (10.5)
2004	94 178 (10.0)	96 589 (9.9)
2005	89 823 (9.5)	90 880 (9.3)
2006-2007	98 998 (10.5)	100 659 (10.3)

Abbreviation: ADHD, attention-deficit/hyperactivity disorder.

[a] Follow-up years were calculated based on whichever condition (anxiety or depression) occurred first.

[b] Body mass index is calculated as weight in kilograms divided by height in meters squared. Categories were established based on age and sex-specific criteria set forth by the Taiwan Ministry of Education,[21] classifying students into one of 4 groups: underweight, normal weight, overweight, or obese.

[c] The classification system provided by Taiwan's Ministry of the Interior was used, which categorizes Taiwan's 368 townships into 5 distinct levels for spatial planning, from level 1 (urban) to level 5 (rural).

cumulative incidence rates, expressed per 1000 person-years, are provided in eTable 11 in Supplement 1.

Female participants in the best-performing quartile of CF (Figure 2A) had the lowest risk of ADHD with a cumulative incidence of 0.18% (95% CI, 0.16%-0.21%), followed by the second (0.24%; 95% CI, 0.21%-0.26%), third (0.27%; 95% CI, 0.25%-0.30%), and fourth quartiles (0.46%; 95% CI, 0.42%-0.49%; *P* < .001). Male students showed a similar pattern, with ADHD risks (Figure 3A) of 0.52% (95% CI, 0.49%-0.55%), 0.68% (95% CI, 0.65%-0.72%), 0.85% (95% CI, 0.81%-0.89%), and 1.19% (95% CI, 1.14%-1.23%) across the same CF quartiles (all *P* < .001).

This dose-dependent association was uniformly observed across ME, MP, and FF: the lowest ADHD risk was noted in the best-performing quartile (Q1), marked at 0.2% (95% CI, 0.18%-0.23%), 0.2% (95% CI, 0.18%-0.23%), and 0.24% (95% CI, 0.21%-0.27%) for female participants (Figure 2A-2D), and at 0.56% (95% CI, 0.53%-0.6%), 0.55% (95% CI, 0.51%-0.58%), and 0.7% (95% CI, 0.66%-0.74%) for male participants (Figure 3A-3D), respectively. In a similar pattern, the cumulative incidences of anxiety and depressive disorders also demonstrated a dose-dependent association with physical fitness levels, where better-performing fitness quartiles were associated with lower risks of these mental disorders.

Correlations Among the 4 Physical Fitness Components

The pairwise correlation coefficients for the 4 physical fitness components were calculated separately for the ANX-DEP and ADHD cohorts, as detailed in eTable 12 and eTable 13 in Supplement 1. ME and MP scores in both cohorts showed positive correlations ($r = 0.39$ for female and $r = 0.46$ for male participants; both *P* < .001). CF scores (the lower, the better) were negatively correlated with ME and MP scores, with correlation coefficients ranging from $r = −0.15$ to $r = −0.47$. This suggests that higher cardiorespiratory fitness is likely associated with better muscular fitness profiles.

Multivariable Cox Proportional Hazards Model for Risks of Anxiety, Depression, and ADHD

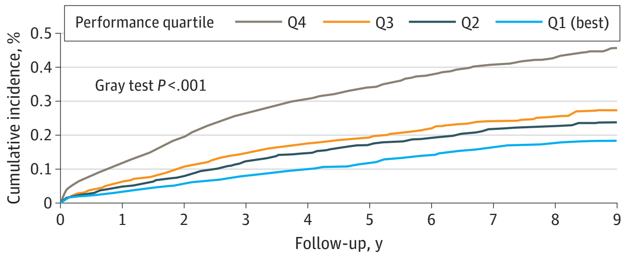
Due to the interrelated nature of physical fitness components, we included all of them in the Cox model. Key results are detailed in **Table 2**. Comprehensive results are presented in eTable 14, eTable 15, and eTable 16 in Supplement 1. In determining the units for our physical fitness measures, we referenced the IQR for female participants in the ANX-DEP cohort, as detailed in Table 1. Specifically, we considered the difference between the lowest-performing quartile and the median to represent a realistic and achievable improvement level.

After adjusting for age, BMI, comorbidities, urbanization, and birth years, a 30-second reduction in 800-m run times, as reflected in CF scores, was associated with a 3% to 8% decrease in the risk of developing a mental disorder. Among female participants, improved CF scores were associated with reduced risks of anxiety (adjusted hazard ratio [aHR], 0.97; 95% CI, 0.96-0.99; *P* < .001), depression (aHR, 0.97; 95% CI, 0.96-0.99; *P* = .001), and ADHD (aHR, 0.92; 95% CI, 0.90-0.94; *P* < .001). Similarly, better CF scores in male participants were associated with lower risks of anxiety (aHR, 0.97; 95% CI, 0.95-0.98; *P* < .001) and ADHD (aHR, 0.93; 95% CI, 0.92-0.94; *P* < .001).

An increase of 5 curl-ups per minute in ME scores was associated with varied outcomes across different mental health conditions. For male participants, enhanced ME scores were associated with a decrease in the risk of anxiety (aHR, 0.97;

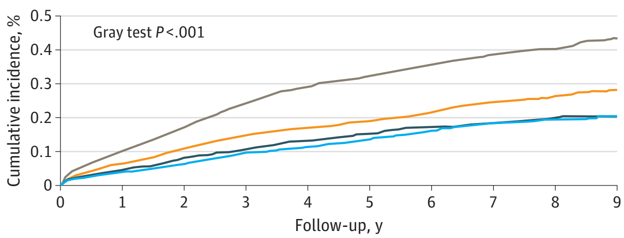
Figure 2. Cumulative Incidence of Attention-Deficit/Hyperactivity Disorder (ADHD) Stratified by Physical Fitness Quartiles in Female Participants

A Cardiorespiratory fitness



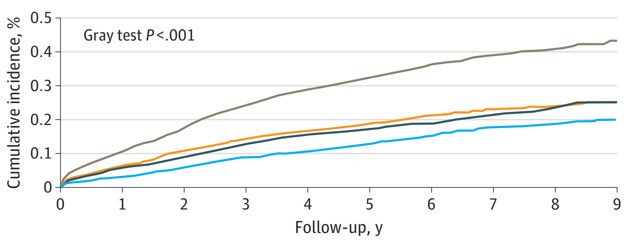
No. at risk										
Q4	231968	231676	220592	203465	186431	167529	141836	112868	75668	29305
Q3	237143	236987	222890	201242	179580	156785	128739	101046	68439	27357
Q2	238962	238829	222443	198160	173478	148420	120255	93402	63039	24921
Q1 (best)	236921	236834	217655	190122	162693	136924	109855	84243	57224	23275

B Muscular endurance



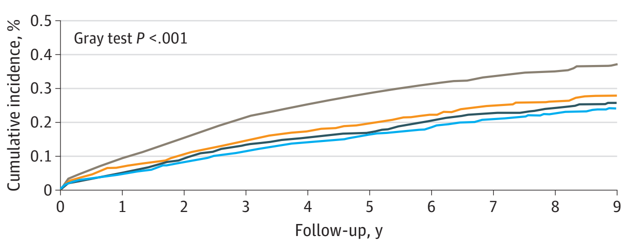
No. at risk										
Q4	268507	268218	252766	230023	206713	182178	151154	118244	77820	29923
Q3	243090	242913	227298	204320	180678	156787	128156	100402	67927	27223
Q2	202295	202194	188743	168748	148460	105290	105290	82369	56404	22843
Q1 (best)	231102	231001	214773	189898	166331	116085	116085	90544	62219	24869

C Muscular power



No. at risk										
Q4	252859	252574	238391	217328	195983	173181	143622	111734	72651	26959
Q3	242081	241917	226110	203442	180013	155996	127257	98896	65859	25658
Q2	228677	228537	212948	189849	166763	143671	117432	91970	62654	25477
Q1 (best)	221377	221298	206131	182370	159423	136810	112374	88959	63206	26764

D Flexibility fitness

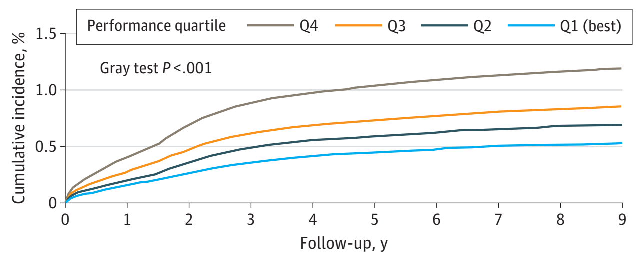


No. at risk										
Q4	280026	279753	265333	242199	218645	192904	161432	127322	85440	34284
Q3	219280	219119	205192	184664	163435	141748	115872	90650	61022	24155
Q2	212020	211904	197448	176170	154900	133500	108585	84432	56975	22336
Q1 (best)	233668	233550	215607	189956	165202	141506	114796	89155	60933	24083

A to D, cumulative incidence of ADHD among female participants, stratified by physical fitness quartiles: A, cardiorespiratory fitness, B, muscular endurance, C, muscular power, and D, flexibility fitness. This analysis spans an 11-year time frame, starting from January 1, 2009, to December 31, 2019. To address reverse causality bias, we implemented a 1-year washout period; thus the actual maximum observation period is capped at 10 years. On the x-axis, the initial marker 0 denotes the commencement of the follow-up period, specifically the 366th day after the physical fitness assessment.

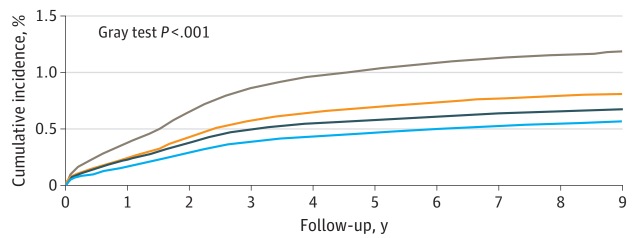
Figure 3. Cumulative Incidence of Attention-Deficit/Hyperactivity Disorder (ADHD) Stratified by Physical Fitness Quartiles in Male Participants

A Cardiorespiratory fitness



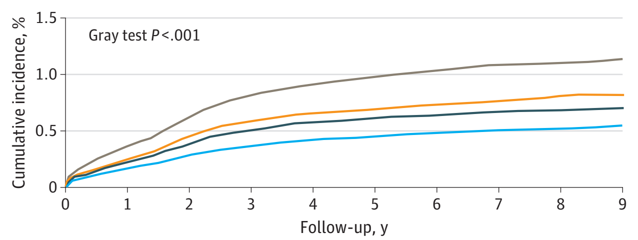
No. at risk										
Q4	239 844	238 873	226 806	208 517	190 179	170 617	144 306	115 512	77 695	30 053
Q3	242 961	242 277	227 155	204 617	182 377	159 053	130 553	102 693	69 422	27 352
Q2	244 311	243 817	227 175	202 780	178 413	153 541	124 832	96 767	64 964	25 598
Q1 (best)	248 401	248 011	228 769	201 178	173 318	146 421	117 809	91 003	62 573	25 951

B Muscular endurance



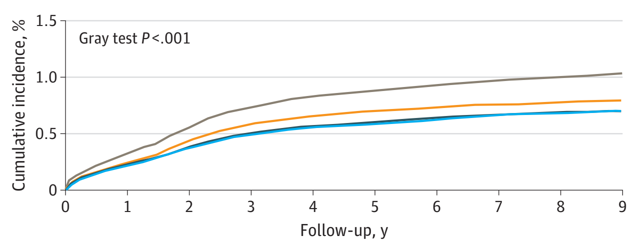
No. at risk										
Q4	246 540	245 602	230 672	209 059	187 407	165 521	137 544	107 811	70 508	26 800
Q3	253 682	253 050	236 403	212 305	188 125	163 476	133 904	105 001	70 773	27 899
Q2	265 142	264 535	247 172	221 390	195 512	169 228	138 789	108 602	74 327	29 829
Q1 (best)	210 153	209 791	195 658	174 338	153 243	131 407	107 263	84 561	59 046	24 426

C Muscular power



No. at risk										
Q4	267 033	266 040	248 967	224 692	200 995	176 343	144 952	112 106	72 003	26 086
Q3	225 540	224 963	209 978	188 822	167 065	144 937	118 036	91 906	60 950	23 506
Q2	249 235	248 668	232 561	208 160	183 828	159 002	130 473	102 498	69 772	27 950
Q1 (best)	233 709	233 307	218 399	195 418	172 399	149 350	124 039	99 465	71 929	31 412

D Flexibility fitness



No. at risk										
Q4	277 073	276 153	260 453	236 707	213 386	188 492	157 294	124 478	83 599	33 396
Q3	228 870	228 300	213 571	191 909	170 057	147 444	120 749	94 617	64 032	25 558
Q2	227 617	227 108	211 726	189 185	166 763	144 001	117 486	91 957	62 412	24 657
Q1 (best)	241 957	241 417	224 155	199 291	174 081	149 695	121 971	94 923	64 611	25 343

A to D display the cumulative incidence of ADHD among male participants, stratified by physical fitness quartiles: A, cardiorespiratory fitness; B, muscular endurance; C, muscular power; and D, flexibility fitness. This analysis spans an 11-year time frame, starting from January 1, 2009, to December 31, 2019. To address reverse causality bias, we implemented a 1-year washout period; thus the actual maximum observation period is capped at 10 years. On the x-axis, the initial marker 0 denotes the commencement of the follow-up period, specifically the 366th day after the physical fitness assessment.

Table 2. Multivariable Cox Proportional Hazards Model for Risk of Mental Disorders by Sex[a]

Disorder	Female aHR (95% CI)	Female P value	Male aHR (95% CI)	Male P value
For anxiety disorder				
Cardiorespiratory fitness, per 30 decremental s	0.97 (0.96-0.99)	<.001	0.97 (0.95-0.98)	<.001
Muscular endurance, per 5 incremental curl-ups	0.99 (0.98-1.01)	.19	0.97 (0.96-0.99)	<.001
Muscular power, per 20 incremental cm	0.94 (0.92-0.96)	<.001	0.93 (0.91-0.96)	<.001
Flexibility fitness, per 5 incremental centimeters	1.01 (0.99-1.02)	.46	0.97 (0.95-0.99)	<.001
For depressive disorder				
Cardiorespiratory fitness, per 30 decremental s	0.97 (0.96-0.99)	.001	0.98 (0.96-1.01)	.13
Muscular endurance, per 5 incremental curl-ups	0.98 (0.96-0.99)	.004	0.98 (0.96-1.01)	.17
Muscular power, per 20 incremental cm	0.98 (0.95-1.01)	.12	0.91 (0.87-0.95)	<.001
Flexibility fitness, per 5 incremental cm	1.02 (1.00-1.03)	.10	0.99 (0.97-1.02)	.46
For ADHD				
Cardiorespiratory fitness, per 30 decremental s	0.92 (0.90-0.94)	<.001	0.93 (0.92-0.94)	<.001
Muscular endurance, per 5 incremental curl-ups	0.94 (0.92-0.97)	<.001	0.96 (0.95-0.97)	<.001
Muscular power, per 20 incremental cm	0.95 (0.91-1.00)	.04	0.96 (0.94-0.99)	.001
Flexibility fitness, per 5 incremental cm	0.97 (0.95-1.00)	.03	0.96 (0.95-0.97)	<.001

Abbreviations: ADHD, attention-deficit/hyperactivity disorder; aHR, adjusted hazard ratio.

[a] All models were adjusted for age, body mass index, comorbidities, urbanization, and birth years. The models for anxiety and depressive disorders were estimated using data from the anxiety and depression (ANX-DEP) cohort. The ANX-DEP cohort included 961 222 female participants and 1 035 411 male participants. The ADHD cohort included 945 028 female participants and 975 568 male participants.

95% CI, 0.96-0.99; *P* < .001). In female participants, a decrease in the risk of depression was observed (aHR, 0.98; 95% CI, 0.96-0.99; *P* = .004). Moreover, both sexes experienced a decreased risk of ADHD, with female participants showing a reduction risk of 6% (aHR, 0.94; 95% CI, 0.92-0.97; *P* < .001) and male participants a 4% reduction (aHR, 0.96; 95% CI, 0.95-0.97; *P* < .001).

A 20-cm increase in MP scores was associated with a 6% reduction in anxiety risk for female participants (aHR, 0.94; 95% CI, 0.92-0.96; *P* < .001) and a 7% reduction for male participants (aHR, 0.93; 95% CI, 0.91-0.96; *P* < .001). This enhancement in MP scores were also associated with a reduced risk of depression, but only for male participants (aHR, 0.91; 95% CI, 0.87-0.95; *P* < .001). Additionally, improved MP scores were associated with a decreased risk of ADHD in both sexes (female participants aHR, 0.95; 95% CI, 0.91-1.00; *P* = .04; male participants aHR, 0.96; 95% CI, 0.94-0.99; *P* = .001).

A 5-cm increase in FF scores was associated with a decreased risk of anxiety in male participants (aHR, 0.97; 95% CI, 0.95-0.99; *P* < .001). Additionally, this improvement in FF scores corresponded with a reduced risk of ADHD for both female participants (aHR, 0.97; 95% CI, 0.95-1.00; *P* = .03) and male participants (aHR, 0.96; 95% CI, 0.95-0.97; *P* < .001).

We investigated the outcomes of potential modifiers, namely sex and income, on the association between physical fitness and mental health by including their interaction terms with the fitness components in the Cox model. This analysis found significant interactions for sex but not for income, supporting the decision to undertake sex-specific analyses (see eTable 17 and eTable 18 in Supplement 1). After adjusting for urbanization, income was not statistically significant. Income data was only available for 56% of participants whose parents were employed in the formal sector. As a result, income was not used as a control variable in our analysis.

Sensitivity Analysis

Sensitivity analyses and robustness checks were conducted to validate our findings. We reevaluated the cumulative incidences of mental disorders with distinct stratifications: physical fitness norms as established by the Taiwan Ministry of Education (eFigure 5, eFigure 6, eFigure 7, eFigure 8, eFigure 9, and eFigure 10 in Supplement 1) and physical fitness quintiles (eFigure 11, eFigure 12, eFigure 13, eFigure 14, eFigure 15, and eFigure 16 in Supplement 1). This approach confirmed a dose-response association, showing that higher physical fitness levels are associated with lower mental disorder risks. We also refined our Cox regression analyses by using quintiles for physical fitness variables instead of their continuous forms (eTable 19, eTable 20, and eTable 21 in Supplement 1), which further reinforced the observed dose-dependent association. Furthermore, analyzing each physical fitness component separately within the Cox model (eTable 22, eTable 23, and eTable 24 in Supplement 1) revealed more pronounced associations with mental disorder risks than the combined model, emphasizing the importance of considering all 4 fitness components in analyses to mitigate the potential for overestimation.

The dynamic association between changes in physical fitness and mental health outcomes was examined by monitoring shifts in fitness percentiles from the entry year to a 1-year follow-up among participants aged 10 to 11 years (eTable 25 in Supplement 1). This revealed that improvements in CF and MP, relative to age and sex-matched peers, were associated with a reduced incidence of mental disorders, highlighting the benefits of fitness enhancement. Additionally, the initial study inclusion criteria required a minimum of 3 years of follow-up. Reducing this requirement to a 2-year minimum follow-up period resulted in minimal changes in the estimated hazard ratios, suggesting the robustness of our findings (eTable 26 in Supplement 1).

Discussion

This national prospective study with 1.9 million children and adolescents shows that lower physical fitness levels, particularly in cardiorespiratory and muscular fitness, are independently associated with higher incidences of anxiety disorders, depressive disorders, and ADHD in children and adolescents, even after controlling for potential confounding factors, such as demographics, BMI, and psychiatric comorbidities. It also highlights how fitness components are differentially associated with mental disorders, with notable sex differences. Our study significantly advances our understanding of the association between physical fitness and mental disorders in children and adolescents.

Physical fitness, notably cardiorespiratory fitness, is linked to better neuropsychological functioning in cognition and executive function, such as cognitive flexibility, working memory, planning, and inhibition control, which are often compromised in youths at risk for mental disorders.[31] Brain imaging studies have also reported that better cardiorespiratory fitness is positively correlated with regional gray matter[32] and white matter volumes,[33] white matter microstructure properties,[34] as well as functional connectivity,[35] impacting neuropsychological functioning and academic performance. These connections between cardiorespiratory fitness with brain structures and functions offer neurobiological insights into the inverse relationship between physical fitness and the risk of mental disorders. As a potential intervention to improve brain health, physical activity can induce neurobiological changes, increasing brain-derived neurotrophic factor,[36] mediating neurogenesis, and the development of key brain areas (frontal lobe, parietal lobe, anterior cingulate cortex, and hippocampus) and white matter tracts.[37]

This longitudinal study is the first in this age group to use clinical diagnosis for assessing anxiety and depressive disorders and ADHD. It supports previous findings that link lower fitness levels with higher psychological stress levels,[38,39] depressive symptoms[13-15,40] and ADHD-related symptoms[12] in children and adolescents. Additionally, our results show a dose-dependent association, consistent with a meta-analysis suggesting lower cardiorespiratory fitness increases the risk of mental disorders, as seen in adult studies.[41]

Previous studies often analyzed just 1 type of fitness[13,42] or used a general fitness measure,[38,39] making comparisons across studies difficult. We used a Cox proportional hazards model with all 4 fitness components to understand the independent effects of each component on mental disorder risks. Consistent with the literature, we found cardiorespiratory fitness most associated with mental health,[11] while the link between flexibility and mental health showed fewer significant associations.[14,15]

The inconsistent results on muscular fitness and mental health might be explained by studies showing that its significant association with depression in youth disappears after adjusting for cardiorespiratory fitness.[15,16] Our study separately analyzed muscular fitness components (ME and MP), revealing that MP in female participants and ME in male participants was not associated with depression risk if considering all 4 fitness components in the Cox model. This suggests that the relationships between muscular fitness and mental disorders are partially influenced by other fitness components.[16] Our findings suggest that models focusing on a single fitness component may overestimate its association with mental disorder risk due to the moderate correlation between cardiorespiratory and muscular fitness.

Sex differences in mental disorder prevalences are well-documented, with girls more often experiencing anxiety and depressive disorders and boys more frequently diagnosed with ADHD.[43,44] However, most studies treat sex merely as a confounding factor instead of exploring how physical fitness affects mental health differently across sexes.[16] Our findings align with 2 studies showing that cardiorespiratory fitness is associated with depressive symptoms in girls but not boys.[45,46] We also found MP as a key association with depression in male participants, possibly due to its greater association with physical self-perception in boys than girls,[47] which impacts mental well-being.[48] Regarding anxiety disorders, our results corroborate a study on college students, showing better cardiorespiratory fitness and muscular power with lower anxiety symptoms in female participants[49] and lower anxiety symptoms in male participants with improved overall physical fitness.[49] These findings highlight the importance of considering sex as a pivotal factor in examining the connection between physical fitness and mental disorders and the need for sex-specific analyses for deeper insights.

Our study provides robust evidence of an inverse association between physical fitness and ADHD risk, a topic rarely explored.[12] Research has shown that lower cardiorespiratory fitness and lower muscular fitness are associated with increased ADHD symptoms in children and adolescents,[12] and young adults,[18] respectively. Using the largest dataset, we discovered that each physical fitness component was independently associated with ADHD risk. Despite known sex differences in ADHD prevalence and symptoms,[44] few studies have investigated this aspect. Our findings reveal a consistent association between fitness components and ADHD risk in boys and girls.

Numerous studies highlight physical activity's positive effects on physical fitness and mental health in children and adolescents,[6,7] contributing to better self-esteem, self-perception,[47] neuropsychological functioning,[50] and reducing mental disorder risks.[6,7] Given a 7.3% decline in cardiorespiratory fitness in the past few decades in wealthier nations,[22] as well as in Taiwan,[21] prioritizing fitness assessment and promoting physical activity is vital for improving youth mental health.[6,51] We suggest that physical fitness should be regularly assessed in schools using simple and standardized tests. Physical fitness may serve as an important indicator to identify those at risk for mental disorders. Additionally, arranging training programs for individuals with the lowest fitness levels is crucial, as minor improvements in fitness have been shown to yield significant health benefits for those who are the least fit.[51] Physical fitness may also be considered a metric for evaluating the effectiveness of physical activity intervention programs for mental health, given its potential role as a mediator between physical activity intervention and mental health outcomes.[8,9]

Strengths and Limitations

Our study has several strengths, including its use of a large, nationwide Taiwanese cohort, making it the most extensive research of its kind. The large sample size ensures sufficient statistical power to analyze gender differences and the independent effects of each physical fitness component. The national cohort approach, automatically enrolling children of certain ages and linking national insurance records, minimizes selection biases common in volunteer-based studies and differential loss to follow-up. Standardized physical fitness assessments, clinical diagnoses of mental disorders, and thorough adjustment for confounders such as BMI, comorbidities, urbanization, and birth years further enhance the study's reliability and validity. By analyzing specific physical fitness components while adjusting for the remaining components, our study significantly advances our understanding of how physical fitness is associated with the risk of developing mental disorders in children and adolescents.

Our study has certain limitations. First, the follow-up beginning at age 10 restricts the generalizability of our results to younger children. Second, due to the timing of our physical assessments, we excluded a substantial number of children diagnosed with ADHD before reaching ages 10 or 11 from the study. Third, as an observational study, our findings do not indicate a direct cause-and-effect relationship between physical fitness and mental disorders. Further research is necessary to clarify the mechanisms connecting physical fitness to the risk of mental disorders. Additionally, pubertal status[52,53] and health-related behaviors, such as screen time[54] and sleep,[55] might be related to both fitness and mental disorders. The lack of these data in the claims data (NHIRD) used in our study prevented us from controlling these factors in the models. Further research is necessary to clarify the mechanisms connecting physical fitness to the risk of mental disorders, taking into account these complex associations.

Conclusions

Our research demonstrates that physical fitness, particularly in cardiorespiratory and muscular fitness domains, is associated with the risk of developing mental disorders in youth. Given the increasing incidences and prevalence of these mental disorders in children and adolescents, our study contributes valuable evidence to the burgeoning field of research exploring the connection between physical fitness and mental health. This finding underscores the need for further research into targeted physical fitness programs, which hold significant potential as primary preventive interventions against mental disorders in children and adolescents.

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Author Affiliations: Department of Psychiatry, National Taiwan University Hospital and College of Medicine, Taipei, Taiwan (Chiang, Gau); Department of Psychiatry, Far Eastern Memorial Hospital, New Taipei City, Taiwan (Chiang, Chuang); International Health Program, College of Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan (Chuang); Institute of Public Health, College of Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan (Chuang, Chen, Liang); Department of Sport Management, National Taiwan University of Sport, Taichung, Taiwan (C.-T. Hsu); The Research Center of Sport and Health Industry, National Sun Yat-sen University, Kaohsiung, Taiwan (C.-T. Hsu, H.-T. Hsu); Department of Physical Education, Fu Jen Catholic University, New Taipei City, Taiwan (Ho); Sports Medicine Center, Fu Jen Catholic Hospital, New Taipei City, Taiwan (Ho); Center for Physical and Health Education, National Sun Yat-sen University, Kaohsiung, Taiwan (H.-T. Hsu); Center for Precision Psychiatry, Massachusetts General Hospital, Boston (Sheu); Department of Psychiatry, Harvard Medical School, Boston, Massachusetts (Sheu); Graduate Institute of Clinical Medicine and Graduate Institute of Brain and Mind Sciences, National Taiwan University College of Medicine, Taipei, Taiwan (Gau); Health Innovation Center, National Yang Ming Chiao Tung University, Taipei, Taiwan (Liang); Research Center for Epidemic Prevention and One Health, National Yang Ming Chiao Tung University, Taipei, Taiwan (Liang).

Author Contributions: Dr Liang had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Chiang, Chuang, C. Hsu, H. Hsu, Gau, Liang.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Chiang, Chuang, Liang.
Critical review of the manuscript for important intellectual content: Chuang, Chen, C. Hsu, Ho, H. Hsu, Sheu, Gau, Liang.
Statistical analysis: Chuang, Chen, C. Hsu, Ho, H. Hsu, Liang.
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