Brazilian Journal of Psychiatry
bjp
Revista Brasileira de Psiquiatria

Braz J Psychiatry. 2023 Sep-Oct;45(5):397-404
doi:10.47626/1516-4446-2023-3156
Brazilian Psychiatric Association

ORIGINAL ARTICLE

Bidirectional associations between hyperopia, myopia, astigmatism, and strabismus, and attention-deficit/hyperactivity disorder in children: a national population-based cohort study

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Objectives: The present study analyzed the reciprocal relationships between four common pediatric ophthalmic diseases (i.e., hyperopia, myopia, astigmatism, and strabismus) and attention-deficit/hyperactivity disorder (ADHD) in children.
Methods: This study enrolled 86,028 children with ADHD and 1,798,673 children without ADHD in the Taiwan Maternal and Child Health Database who were born at any time from 2004 to 2017. Cox proportional hazards regression models were used to estimate the bidirectional relationships of the four ophthalmic diseases with ADHD in children after adjusting for age, sex, and gestational age at birth. Survival curves for time-to-event variables were estimated using the Kaplan-Meier method, and the log-rank test was used to compare the curves.
Results: The results indicated that ADHD significantly predicted the occurrence of hyperopia, myopia, astigmatism, and strabismus. Furthermore, hyperopia, myopia, astigmatism, and strabismus significantly predicted the occurrence of ADHD. The time between enrollment and ADHD diagnosis was shorter for patients with ophthalmic diseases than for the control group, and the time between enrollment and ophthalmic disease diagnosis was also shorter for ADHD patients than for the control group. Sex differences were found in the associations between ADHD and ophthalmic diseases.
Conclusion: Clinicians should monitor children with ADHD for hyperopia, myopia, astigmatism, and strabismus to ensure appropriate treatment, and vice versa.

Keywords: Attention deficit hyperactivity disorder; hyperopia; myopia; astigmatism; strabismus

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a common neuropsychiatric disorder.[1] A systematic review and meta-analysis published in 2015 estimated that the prevalence of ADHD was 7.2%.[2] The U.S. National Survey of Children's Health found that the prevalence of ADHD was 9.4%.[3] A study using a nationally representative sample of children in Taiwan reported a lifetime ADHD prevalence of 10.1%.[4] ADHD is more prevalent among boys (at a 2:1 ratio).[1] The core symptoms of ADHD, including inattention, hyperactivity, and impulsivity, can cause learning and interpersonal difficulties, academic underachievement, and rule-breaking at school,[5] are similar to those observed among those in children with ophthalmic problems. A growing number of studies have suggested an association between ophthalmic diseases and ADHD in children.[1,2] Refractive errors, including myopia, hyperopia, and astigmatism, are the most common ophthalmic disorders among children.[3] Refractive errors not only increase the possibility of pathological changes in the eye, such as myopic macular degeneration and retinal detachment, but may also lead to irreversible blindness.[4] Refractive errors also greatly influence the learning ability of children, which can limit their educational performance and opportunities.[4] Strabismus, another prevalent ophthalmic disease that leads to visual impairment, can increase the risk of emotional

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Submitted Apr 09 2023, accepted Jun 25 2023.

How to cite this article: Chou W-P, Chen Y-L, Hsiao RC, Lai Y-H, Yen C-F. Bidirectional associations between hyperopia, myopia, astigmatism, and strabismus, and attention-deficit/hyperactivity disorder in children: a national population-based cohort study. Braz J Psychiatry. 2023;45:397-404. http://doi.org/10.47626/1516-4446-2023-3156

problems, low self-esteem, bullying victimization, and social anxiety in children.[5]

There has been an increasing trend in the prevalence of myopia over the past half-century.[6] In Australian children aged 12 years, the prevalence of myopia was 8.6% among those of European descent and 52.5% among those of East Asian descent.[7] A Brazilian study found an overall myopia prevalence of 25.3%,[8] with rates in the 20% range for children aged 1 to 9 years and in the 30% range for children aged 10 to 19 years. In Taiwan, the prevalence of myopia was 25.4% for 7-year-olds and 76.7% for 12-year-olds in 2016.[9] No sex differences in myopia prevalence were observed in either Brazil or Taiwan. The reported prevalence of significant hyperopia in Australian children aged 12 years was 3% among those of European descent and 3.3% among those of East Asian descent.[7] In Brazil, hyperopia was more frequent among individuals aged 40 years or older, and a significantly higher proportion of women had hyperopia than men in this age group (65.6% vs. 55.6%).[8] For preschool-aged children in Taiwan, the prevalence of significant hyperopia was 5%, with no sex difference found.[10] Comparing the prevalence of astigmatism between studies is challenging due to variations in definition and differences in population age ranges.[11] The prevalence of astigmatism in a Brazilian population was reported as 59.7%.[8] A Taiwanese study found that 51% of school children had astigmatism,[11] while another study focusing on preschool children reported a prevalence of 49%.[12] Neither of these studies found a sex difference in the prevalence of astigmatism. In the USA, the prevalence of astigmatism of more than 1.0 diopter was 29% among children aged 0 to 9.5 years and 39% among children aged 0 to 6 years.[13,14] The estimated prevalence of strabismus worldwide was 2%.[15] In Taiwan, the prevalence of strabismus among preschool-aged children was approximately 1%, with no sex difference observed.[10] However, there is currently no other data on the prevalence of strabismus among children aged 6 to 13 years in Taiwan. One Chinese study reported that the prevalence of strabismus was 5.02% among children aged 10 to 16 years,[16] while another found prevalence rates of 5.63% for girls and 5.66% for boys among children aged 6 to 72 months.[17]

A systematic review and meta-analysis demonstrated that people with ADHD had a significantly higher risk of hyperopia, astigmatism, and strabismus than those without ADHD; however, individuals with vision problems did not have a higher risk of ADHD than people without them.[18] Some topics on the association between ADHD and ophthalmic diseases warrant further study. First, only a few cohort studies with large sample sizes have examined the temporal association between ADHD and ophthalmic diseases. One study using data from the Taiwan National Health Insurance Research Database revealed a higher cumulative incidence of ADHD in children with strabismus during the follow-up period.[19] Cohort studies have not examined the predictive values of hyperopia, myopia, or astigmatism for ADHD incidence. Second, most relevant studies on the association between ADHD and ophthalmic diseases have enrolled clinically referred populations; therefore, their generalizability is limited due to selection bias.[1] Moreover, research has indicated sex difference in ADHD prevalence[20]; a review found that in the USA, women are at a higher risk of visual impairment,[21] whereas no sex differences were found in the prevalence of hyperopia, myopia, astigmatism, or strabismus among children.[8-12] Thus, a large, representative sample of female participants is required to verify the association between ADHD and ophthalmic diseases in children. Third, studies have demonstrated that preterm birth increases the risks of ADHD[22] and ophthalmic diseases[23]; therefore, studies examining the association between ADHD and ophthalmic diseases in children should control for gestational age.

This nationwide population-based cohort study investigated the bidirectional associations between four common pediatric ophthalmic diseases (i.e., hyperopia, myopia, astigmatism, and strabismus) and ADHD in children, including sex differences in the associations. We hypothesized that children with ADHD would have an increased risk of incident hyperopia, myopia, astigmatism, and strabismus, and vice versa, compared to children without ADHD during the follow-up period. We also hypothesized that there were sex differences in the association between ADHD and ophthalmic diseases.

Methods

The present study was conducted in August 2022 and enrolled children in the Taiwan Maternal and Child Health Database (TMCHD) who were born between 2004 and 2017 and had complete information on gestational age at birth. The TMCHD has recorded data on 99.78% of births in Taiwan since 2004.[24] TMCHD data were retrieved from the Taiwan Birth Registration Database, Birth Certificate Application, the National Register of Death, and the National Health Insurance Research Database.

Study population, exposure, and outcome

We employed the ICD-9-CM and ICD-10 for disease identification. Specifically, we employed the codes for hyperopia (ICD-9-CM code 367.0; ICD-10 code H52.0), myopia (ICD-9-CM codes 360.21 and 367.1; ICD-10 codes H44.2 and H52.1), astigmatism (ICD-9-CM codes 367.20-367.22; ICD-10 code H52.2), and strabismus (ICD-9-CM codes 277.8, 378.50-378.53, 378.00-378.13; ICD-10 codes H49.00-H49.4, H49.8, H49.9, H50.0-H50.6, H50.8, H50.9), and ADHD (ICD-9-CM code 314; ICD-10 code F90). The diagnoses of hyperopia, myopia, astigmatism, and strabismus were documented by board-certified ophthalmologists based on clinical judgement and the results of history taking and instrument inspection. The diagnosis of ADHD was documented by board-certified psychiatrists based on the results of clinical diagnostic interviews with children and their main caregivers, teacher reports, and attention tests.

Analysis 1: ADHD as a risk factor for ophthalmic disorders

This bidirectional cohort study investigated the temporal association between ADHD and four ophthalmic diseases. In Analysis 1, we included children who received two or more outpatient diagnoses or one inpatient diagnosis of ADHD as the case group. This study recruited children who were at least 5 years old (to allow enough time to observe symptoms and increase the accuracy of ADHD diagnosis); the other children served as the non-ADHD group. The maximum age for inclusion was 14 years old. The index date for these children was the birthdate.

The primary outcome was new-onset hyperopia, myopia, astigmatism, or strabismus. To identify the onset of four ophthalmic diseases in the ADHD and control cohort, participants with a previous diagnosis of hyperopia, myopia, astigmatism, and strabismus were excluded. Patients were considered to have hyperopia, myopia, astigmatism, or strabismus if they received two or more outpatient diagnoses or one inpatient diagnosis during the follow-up period, which lasted from January 1, 2004 to the time of diagnosis, death, or until the end of the research period (December 31, 2018).

Analysis 2: ophthalmic disorders as a risk factor for ADHD

In Analysis 2, we included children who received two or more outpatient diagnoses or one inpatient diagnosis of an ophthalmic disease (hyperopia, myopia, astigmatism, or strabismus) as the case group, and the other children served as non-ophthalmic disease group. The index date for these children was the birthdate. The primary outcome was new-onset ADHD. To identify new-onset ADHD, we excluded participants with a previous diagnosis of ADHD. Patients were considered to have ADHD if they received two or more outpatient diagnoses or one inpatient diagnosis during the follow-up period, which lasted from January 1, 2004 to the time of diagnosis, death, or until the end of the research period (December 31, 2018).

Covariates

The covariates in this study were year of birth, sex, and gestational age at birth.

Statistical analyses

Categorical variables were reported as frequency and proportion, while continuous variables were reported as mean and SD. To estimate the difference between the case and control groups, Pearson's χ^2 test was applied to compare categorical variables, and an independent *t*-test was used to compare continuous variables. We used Cox proportional hazards regression models with time-on-study as the time scale to determine the reciprocal association between ophthalmic diseases and ADHD, adjusting for sex, year of birth, and gestational age at birth. We also added the interaction of sex with ADHD and ophthalmic diseases into the Cox regression models to examine the sex differences in the associations between ADHD and ophthalmic diseases. Adjusted hazard ratios with 95% CI were used to verify longitudinal associations. HR is the ratio that an event of interest occurs during the follow-up period in the exposed group compared to the unexposed group. A HR of 1 indicates no difference between the groups. The adjusted hazard ratio considers potential confounding variables that could influence the event. It estimates the hazard by holding other confounders constant. Survival curves for time-to-event variables were estimated using the Kaplan-Meier method; the log-rank test was used to compare the survival curves. Schoenfeld residuals were used to examine the assumption of proportional hazard between groups.

Ethics statement

This study was approved by the research ethics committee of China Medical University Hospital (approval number CMUH108-REC1-142).

Results

This study included a total of 86,028 children with ADHD (67,107 boys and 18,921 girls) and 1,798,673 children without ADHD (915,601 boys and 883,072 girls). The demographic characteristics of children with and without ADHD are presented in Table 1. There was a significantly higher proportion of boys in the ADHD group than the non-ADHD group (78% vs. 50.9%, $p < 0.001$). Children with ADHD had significantly higher incidences of all types of ophthalmic diseases, including hyperopia (3.5% vs. 1.9%, $p < 0.001$), myopia (29.6% vs. 23.8%, $p < 0.001$), astigmatism (11.2% vs. 7.4%, $p < 0.001$), and strabismus (2% vs. 0.8%, $p < 0.001$) than the non-ADHD group. The demographic characteristics, gestational age, and ADHD diagnostic status of children with and without ophthalmic diseases are presented in Table 2. Children with ophthalmic diseases had a significantly higher incidence of ADHD than children without them (all $p < 0.001$).

As indicated in Table 3, the first Cox regression model revealed that children with ADHD had a higher risk of all types of ophthalmic diseases than those without ADHD. Based on the Schoenfeld residuals test, the proportional hazard held between groups. After adjusting for covariates, the risk of ophthalmic diseases ranged from 1.08 to 2.28 ($p < 0.001$); children with strabismus had the highest risk, followed by those with hyperopia, astigmatism, and myopia in decreasing order. The Kaplan-Meier survival curves revealed a shorter time between enrollment and the occurrence of ADHD in patients with ophthalmic diseases than in controls (Figures 1A to 1D).

The second Cox regression model revealed that children with any type of ophthalmic disease had a higher risk of ADHD than children without ophthalmic diseases. After year of birth, sex, and gestational age at birth were controlled for, the risk of ADHD ranged from 1.07 to 2.25 ($p < 0.001$); children with strabismus had the highest risk, followed by those diagnosed with f hyperopia, astigmatism, and myopia in decreasing order. The Kaplan-Meier survival curves revealed a shorter time between enrollment and the occurrence of ophthalmic disease in

Table 1 Demographic characteristics, gestational age, and common ophthalmic diseases of children with and without attention-deficit/hyperactivity disorder (ADHD)

	ADHD (n=86,028)	Non-ADHD (n=1,798,673)	Statistics
Age (years), mean (SD)	10.4 (2.6)	9.5 (2.9)	$t = 98.64$, $p < 0.001$
Year of birth			
2004	11,810 (13.7)	188,013 (10.5)	$\chi^2 = 12975.80$, $p < 0.001$
2005	11,352 (13.2)	180,983 (10.1)	
2006	10,808 (12.6)	180,703 (10.0)	
2007	10,893 (12.7)	182,653 (10.2)	
2008	10,261 (11.9)	178,126 (9.9)	
2009	9,316 (10.8)	176,698 (9.8)	
2010	7,000 (8.1)	144,480 (8.0)	
2011	6,407 (7.4)	176,635 (9.8)	
2012	5,034 (5.9)	201,567 (11.2)	
2013	3,147 (3.7)	188,815 (10.5)	
Gestational age (weeks), mean (SD)	38.1 (1.9)	38.3 (1.6)	$t = 30.36$, $p = < 0.001$
Sex			
Male	67,107 (78.0)	915,601 (50.9)	$\chi^2 = 24164.73$, $p < 0.001$
Female	18,921 (22.0)	883,072 (49.1)	
Ophthalmic diseases			
Hyperopia	3,025 (3.5)	34,809 (1.9)	$\chi^2 = 1042.48$, $p < 0.001$
Myopia	25,494 (29.6)	427,260 (23.8)	$\chi^2 = 1555.12$, $p < 0.001$
Astigmatism	9,659 (11.2)	132,996 (7.4)	$\chi^2 = 1724.12$, $p < 0.001$
Strabismus	1,719 (2.0)	15,155 (0.8)	$\chi^2 = 1234.39$, $p < 0.001$
Any	31,394 (36.5)	501,322 (27.9)	$\chi^2 = 3008.99$, $p < 0.001$

Data presented as n (%).

patients with ADHD than in those without ADHD (Figures 1E to 1H).

Table 4 shows the results of the Cox regression models by adding the interaction between sex (reference group = boys), ADHD, and ophthalmic disease. The first Cox regression model revealed that the interaction between sex and ADHD was significantly associated with all types of ophthalmic diseases. The results indicated that girls with ADHD had a higher risk of all types of ophthalmic diseases than boys with ADHD. The second Cox regression model revealed that, except for the interaction between sex and myopia, the interaction between sex and all types of ophthalmic disease was significantly associated with ADHD. The results indicated that girls with hyperopia, astigmatism, and strabismus had a higher risk of ADHD than boys with hyperopia, astigmatism, and strabismus, respectively.

Discussion

This population-based cohort study is the first to examine the temporal relationship between ADHD and ophthalmic diseases in a large representative population. Its results demonstrate bidirectional associations between ADHD and hyperopia, myopia, astigmatism, and strabismus. The present study also demonstrated sex differences in the associations between ADHD and ophthalmic diseases.

The associations between ADHD and ophthalmic diseases may involve several mechanisms. First, the reciprocal relationships between ADHD and strabismus were stronger than those between ADHD and other ophthalmological diseases. ADHD symptoms have been associated with functional abnormalities in the left subgyral white matter of the frontal lobe, right medial frontal gyrus, right cingulate, and frontal lobe.[25] It has also been reported that white matter integrity in the cingulum is compromised in children with ADHD.[26] Interestingly, a functional magnetic resonance imaging study found that, compared to controls, individuals with strabismus had significantly lower fractional amplitude of low-frequency fluctuation values in the left frontal superior medial gyrus and the right middle cingulum.[27] These studies suggest that strabismus and ADHD may share common structural anomalies in the central nervous system. Second, shared risk factors might account for the associations between ADHD and ophthalmological diseases. Since studies have found that preterm birth increases the risk of ADHD[28] and visual deficits, such as reduced visual acuity, strabismus, abnormal stereopsis, and refractive error,[29] the present study controlled for the effect of gestational age at birth. Other potential shared risk factors warrant study. For example, inattention, hyperactivity, and strabismus can be found in patients with some rare genetic conditions, such as Xia-Gibbs syndrome[30]; however, genome-wide association studies have found no significant genetic associations between ADHD and ophthalmological diseases.[31] Third, children with ADHD are more likely to overuse smartphones and the Internet than those without ADHD.[32] Activities that require the eyes to focus on near objects for a prolonged period may cause hyperopic defocus, thus increasing the risk of myopia.[33] Fourth, visual impairment can negatively affect executive function and attention and lead to symptoms of inattention and hyperactivity.[34]

Table 2 Demographic characteristics, gestational age, and attention-deficit/hyperactivity disorder (ADHD) diagnosis in children with and without ophthalmic diseases

	Hyperopia		Statistics	Myopia		Statistics	Astigmatism		Statistics	Strabismus		Statistics
	Yes (n=37,834)	No (n=1,846,867)		Yes (n=452,754)	No (n=1,431,947)		Yes (n=142,655)	No (n=1,742,046)		Yes (n=16,874)	No (n=1,867,827)	
Age (years), mean (SD)	10.0 (2.7)	9.5 (2.9)	t = 32.40 $p < 0.001$	11.4 (2.2)	9.0 (2.9)	t = 589.71 $p < 0.001$	10.6 (2.6)	9.5 (2.9)	t = 152.23 $p < 0.001$	10.0 (2.8)	9.5 (2.9)	t = 23.08 $p < 0.001$
Year of birth												
2004	4,157 (11.0)	195,666 (10.6)	χ^2 = 6661.37 $p < 0.001$	89,100 (19.7)	110,723 (7.7)	χ^2 = 210289.83 $p < 0.001$	21,418 (15.0)	178,405 (10.2)	χ^2 = 23714.57 $p < 0.001$	2,038 (12.1)	197,785 (10.6)	χ^2 = 5211.68 $p < 0.001$
2005	4,107 (10.9)	188,228 (10.2)		80,901 (17.9)	111,434 (7.8)		20,029 (14.0)	172,306 (9.9)		2,020 (12.0)	190,315 (10.2)	
2006	4,222 (11.2)	187,289 (10.1)		73,749 (16.3)	117,762 (8.2)		19,234 (13.5)	172,277 (9.9)		1,867 (11.1)	189,644 (10.2)	
2007	4,608 (12.2)	188,938 (10.2)		65,066 (14.4)	128,480 (9.0)		18,561 (13.0)	174,985 (10.0)		1,999 (11.8)	191,547 (10.3)	
2008	4,535 (12.0)	183,852 (10.0)		52,537 (11.6)	135,850 (9.5)		16,585 (11.6)	171,802 (9.9)		1,771 (10.5)	186,616 (10.0)	
2009	4,462 (11.8)	181,552 (9.8)		40,648 (9.0)	145,366 (10.2)		14,894 (10.4)	171,120 (9.8)		1,745 (10.3)	184,269 (9.9)	
2010	3,386 (8.9)	148,094 (8.0)		21,929 (4.8)	129,551 (9.0)		10,238 (7.2)	141,242 (8.1)		1,343 (8.0)	150,137 (8.0)	
2011	3,553 (9.4)	179,489 (9.7)		16,053 (3.5)	166,989 (11.7)		9,829 (6.9)	173,213 (9.9)		1,571 (9.3)	181,471 (9.7)	
2012	3,024 (8.0)	203,577 (11.0)		8,960 (2.0)	197,641 (13.8)		7,826 (5.5)	198,775 (11.4)		1,425 (8.4)	205,176 (11.0)	
2013	1,780 (4.7)	190,182 (10.3)		3,811 (0.8)	188,151 (13.1)		4,041 (2.8)	187,921 (10.8)		1,095 (6.5)	190,867 (10.2)	
Gestational age (weeks), mean (SD)	37.9 (2.2)	38.3 (1.7)	t = 33.38 $p < 0.001$	38.4 (1.6)	38.3 (1.8)	t = 35.54 $p < 0.001$	38.2 (1.9)	38.3 (1.7)	t = 19.26 $p < 0.001$	37.6 (2.7)	38.3 (1.7)	t = 33.62 $p < 0.001$
Sex												
Male	18,356 (48.5)	964,352 (52.2)	χ^2 = 203.06 $p < 0.001$	232,131 (51.3)	750,577 (52.4)	χ^2 = 180.88 $p < 0.001$	71,987 (50.5)	910,721 (52.3)	χ^2 = 174.28 $p < 0.001$	8,099 (48.0)	974,609 (52.2)	χ^2 = 117.03 $p < 0.001$
Female	19,478 (51.5)	882,515 (47.8)		220,623 (48.7)	681,370 (47.6)		70,668 (49.5)	831,325 (47.7)		8,775 (52.0)	893,218 (47.8)	
ADHD	3,025 (8.0)	83,003 (4.5)	χ^2 = 1042.48 $p < 0.001$	25,494 (5.6)	60,534 (4.2)	χ^2 = 1,555.12 $p < 0.001$	9,659 (6.8)	76,369 (4.4)	χ^2 = 1724.12 $p < 0.001$	1,719 (10.2)	84,309 (4.5)	χ^2 = 1234.39 $p < 0.001$

Data presented as n (%).

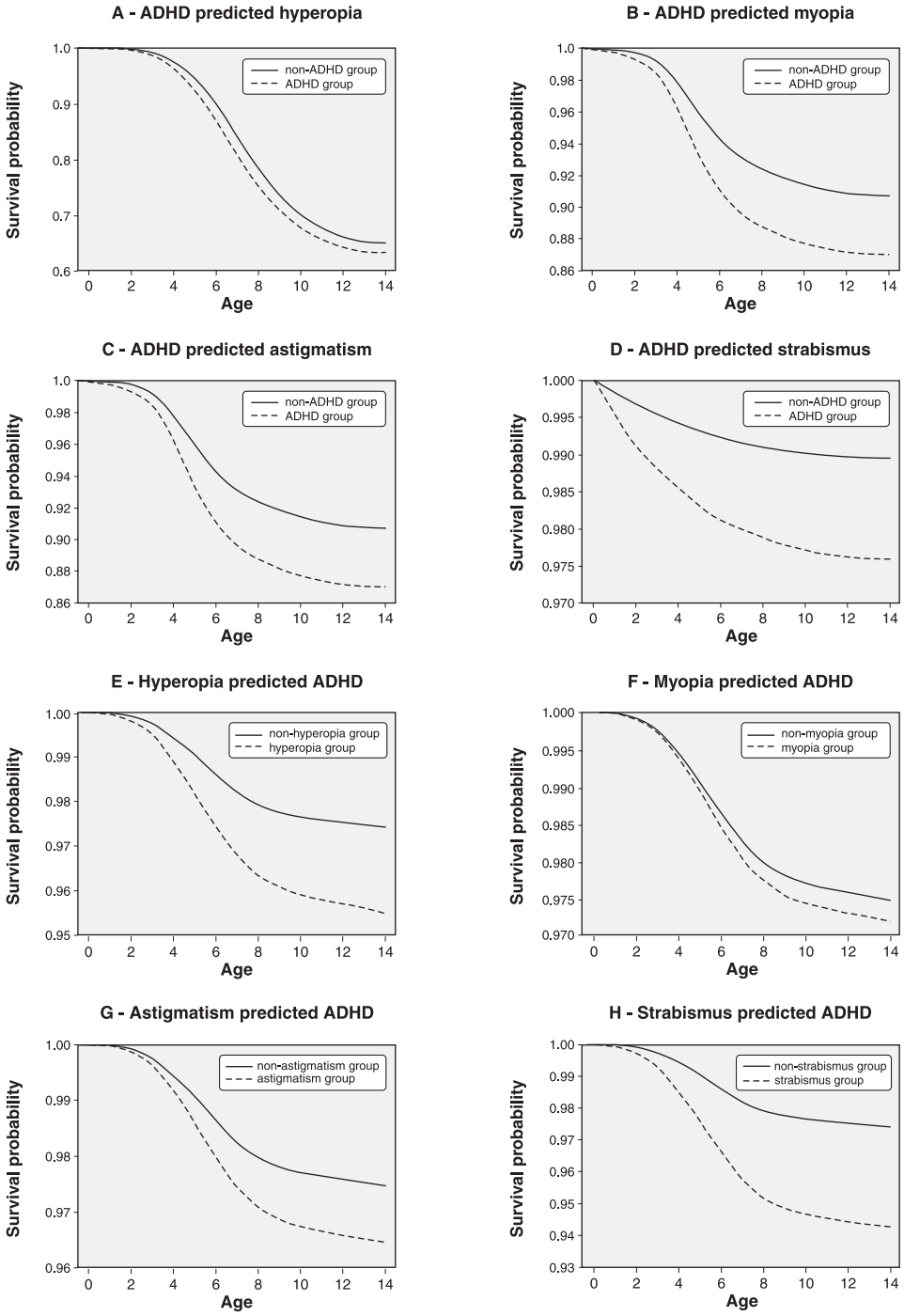

Figure 1 Kaplan-Meier curves of ophthalmic disease-free survival for patients with attention-deficit/hyperactivity disorder (ADHD) and controls (A to D). Kaplan-Meier curves of ADHD-free survival for patients with ophthalmic diseases and controls (E to H). All log-rank test p-values were < 0.001.

The present study demonstrated that girls with ADHD had a higher risk of all four ophthalmic diseases than boys with ADHD, and that girls with hyperopia, astigmatism, and strabismus had a higher risk of ADHD than boys with hyperopia, astigmatism, and strabismus, respectively. This study is the first to identify sex differences in the associations between ADHD and ophthalmic diseases. The mechanisms accounting for the sex differences require further study.

We offer suggestions based on the results. First, since ADHD and ophthalmological diseases have reciprocally predictive effects, clinicians should monitor children with ADHD for hyperopia, myopia, astigmatism, and strabismus to ensure appropriate treatment. Children with

Table 3 Associations between ADHD and common ophthalmic diseases in children[†]

Model	aHR
ADHD predicted ophthalmic disease	
Hyperopia	1.77 (1.70-1.83)
Myopia	1.08 (1.07-1.10)
Astigmatism	1.40 (1.37-1.43)
Strabismus	2.28 (2.17-2.40)
Any ophthalmic disease	1.20 (1.18-1.21)
Ophthalmic diseases predicted ADHD	
Hyperopia	1.75 (1.69-1.82)
Myopia	1.07 (1.05-1.09)
Astigmatism	1.40 (1.37-1.43)
Strabismus	2.25 (2.15-2.37)
Any ophthalmic disease	1.21 (1.19-1.23)

ADHD = attention-deficit/hyperactivity disorder; aHR = adjusted hazard ratio.
[†] Controlled for sex, gestational age, and year of birth.

Table 4 Interaction of the associations between ADHD and common ophthalmic diseases in children according to sex[†]

Model	Multiplicative interaction of sex aHR (95%CI)
ADHD predicted ophthalmic diseases	
Hyperopia	1.29 (1.19-1.40)
Myopia	1.03 (1.00-1.06)
Astigmatism	1.21 (1.15-1.26)
Strabismus	1.39 (1.25-1.55)
Any ophthalmic disease	1.11 (1.08-1.14)
Ophthalmic disease predicted ADHD	
Hyperopia	1.32 (1.22-1.43)
Myopia	1.01 (0.97-1.05)
Astigmatism	1.23 (1.17-1.29)
Strabismus	1.46 (1.31-1.61)
Any ophthalmic disease	1.10 (1.07-1.14)

ADHD = attention-deficit/hyperactivity disorder; aHR = adjusted hazard ratio.
[†] Controlled for sex, gestational age, and calendar year of birth; reference group = boys.

ophthalmic diseases should also be monitored for ADHD symptoms. Ophthalmic diseases should be screened in children who suffer from inattention and inattention-related learning difficulties. Early detection and treatment of ophthalmic diseases may reduce the chance of misdiagnosis as ADHD. Second, there were sex differences in the associations between ADHD and ophthalmic diseases. There is evidence that girls have more internalizing behaviors (e.g., anxiety, low self-esteem) and fewer externalizing behaviors (e.g., hyperactivity), leading to a risk of late- and under-diagnosis.[35] Therefore, the risks of ADHD and ophthalmic diseases in girls warrant careful evaluation.

This study has several limitations. First, whether its results can be generalized to Taiwanese children who did not seek treatment for ADHD and ophthalmic diseases or to non-Taiwanese people remains unclear. Incorrectly treated ophthalmic diseases may result in concentration difficulties at school and subsequent academic impairment. These outcomes could be confused with clinical features typically found in children with ADHD. Second, we did not determine the effects of treatment for ADHD and ophthalmic diseases. Whether ADHD medication or vision correction can alter the associations between ADHD and ophthalmic diseases warrants further study. Third, since the TMCHD does not contain information on disease severity, we could not evaluate the influence of this variable.

In conclusion, children with ADHD had a higher risk of developing hyperopia, myopia, astigmatism, and strabismus than children without ADHD. Furthermore, children with these four ophthalmic diseases had a higher risk of developing ADHD than the control group. Further research is required to investigate the pathogenic mechanisms shared between ADHD and these four ophthalmic diseases.

Acknowledgements

This study was supported by grants from the Ministry of Science and Technology (MOST: 109-2314-B-468-001-MY2), Taiwan. The funding agency had no role in this study.

Disclosure

The authors report no conflicts of interest.

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