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NEUROPHTHALMOLOGY

# Frequencies and patterns of symptoms in Chinese adults with accommodative and binocular dysfunctions

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## Abstract

**Purpose** Recent studies have found that children with convergence insufficiency experience higher frequencies of performance-related symptoms (e.g., losing concentration), but data on performance-related symptoms among adults with accommodative dysfunctions (ADs) and/or binocular dysfunctions (BDs) are lacking, which might cause misdiagnosis, diagnostic confusion, or exacerbation of attention deficits. We aimed to describe frequencies and symptom patterns in adults with ADs and/or BDs who were treated at optometric clinics and explore any correlations between visual symptoms and clinical findings.

**Methods** This cross-sectional study divided 235 participants (age: $23.7 \pm 2.9$ years) into three groups: ADs, BDs, and normal binocular vision (NBV) groups. Convergence Insufficiency Symptom Survey (CISS), refractive examinations, and binocular tests were administered to all participants. After 1-to-1 propensity score matching, outcomes were assessed using Mann−Whitney *U* test and Pearson's correlation analysis among three groups.

**Results** In this sample, the number (frequency) of individuals with ADs and/or BDs was 117 (49.8%). ADs and BDs groups experienced significantly more performance-related symptoms (feeling sleepy, losing concentration, trouble remembering, reading slowly, losing place, and having to re-read; all $P < 0.05$) than the NBV group. Significant correlations were observed between performance-related symptoms and clinical findings, including accommodative amplitude ($r = -0.294$), accommodative facility ($r = -0.452$), near phoria ($r = -0.261$), near point of convergence ($r = 0.482$), and positive fusional vergence ($r = -0.331$) (all $P < 0.001$).

**Conclusion** ADs and/or BDs are commonly present in adults treated at optometric clinics, and adults diagnosed with ADs and/or BDs exhibit more performance-related symptoms than participants with NBV.

**Keywords** Performance-related symptoms · Eye-related symptoms · Accommodative dysfunctions · Binocular dysfunctions

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**Key messages**

- Accommodative dysfunctions (ADs) and binocular dysfunctions (BDs) are common in pediatric populations. Recent studies have found that children with convergence insufficiency have higher frequencies of performance-related symptoms (e.g., losing concentration) than eye-related symptoms.
- This study found that ADs and/or BDs are also common in adult Chinese clinical optometry patients.
- Adults with ADs and/or BDs exhibit frequent and severe performance-related symptoms compared to those with normal binocular vision.

## Introduction

Accommodative dysfunctions (ADs) and binocular dysfunctions (BDs) are reported to be the second most common anomalies encountered in optometric clinics other than refractive error [1]. The frequency of these anomalies has been extensively studied in various populations, but mostly in pediatric populations [2, 3] or high school/university students [4]. However, little is known about the frequency of these anomalies in adults. This population is of great interest because the young adult workforce has the highest load of near-work activities of any population, and the presence of ADs and/or BDs may result in visual symptoms that affect their occupation, athletic performance, and leisure activities [1].

Recently, child-reported symptoms associated with ADs and/or BDs have been quantified using the convergence insufficiency symptom survey (CISS) [2, 5], which is a validated questionnaire with 15 items designed to investigate the most common symptoms and quantify the severity of symptoms in binocular vision studies [5, 6]. The CISS was divided into two subscales: the performance-related subscale, which comprised six symptoms related to visual efficiency when reading or performing near work (e.g., losing place and losing concentration), and the eye-related subscale, which comprised nine symptoms specific to visual function or asthenopic-type complaints, such as words blurring and eyes hurting [7, 8]. Several studies found that children with convergence insufficiency and/or ADs more frequently reported performance-related symptoms than eye-related symptoms [7, 8], which are similar to behaviors associated with attention deficits, such as trouble sustaining attention during tasks or play activities [7, 9]. However, the symptom patterns and severity (especially of performance-related symptoms) in adults with ADs and/or BDs, who may have greater periods of prolonged near-task demands and are more likely to manifest visual symptoms [10], are unknown.

Recent studies have found significant correlations between the overall CISS score and clinical findings of convergence insufficiency (such as near point of convergence and positive fusional vergence) [6], but they did not investigate whether the performance-related subscales or eye-related subscales correlate with the clinical findings. Distinguishing between different visual symptom patterns of ADs and/or BDs is especially important because accurate assessment of adults' visual symptoms informs decisions regarding diagnoses and treatment; indeed, most patients consult optometrists because their visual symptoms negatively affect their daily life. Moreover, treatments might differ for performance-related and eye-related symptoms [7, 11]. Thus, further investigation is needed.

Accordingly, we aimed to conduct a cross-sectional study to determine the frequencies of ADs and/or BDs in Chinese adults treated at an optometric clinic and to describe symptom patterns and severity in patients with ADs and/or BDs according to CISS. We hypothesized that (1) ADs and/or BDs are commonly present in Chinese adults treated at optometric clinics, (2) participants with ADs and/or BDs will exhibit more performance-related symptoms than participants with normal binocular vision (NBV), and (3) significant associations between clinical findings and performance-related symptoms would be found and suggest that adults with defective clinical measures are likely to be symptomatic and should be referred for a comprehensive eye examination.

## Methods

### Participants

This study employed a prospective cross-sectional clinic-based design. Participants were recruited through

**Table 1** Diagnostic criteria for non-strabismic binocular and accommodative dysfunctions

| | |
|---|---|
| Convergence insufficiency | Requires 1, 2, and 3<br>1. Near exophoria at least 4△ greater than distance exophoria<br>2. NPC break point ≥ 6 cm<br>3. Reduced near PFV (break point ≤ 15△ or failed Sheard's criterion) |
| Convergence excess | Requires 1 and at least 1 sign from 2 ~ 3<br>1. Near esophoria greater than distance esophoria by ≥ 4△<br>2. Reduced near NFV, ≤ 8/16/7 for blur, break, and recovery (at least one of three)<br>3. Near VF ≤ 12 cpm |
| Divergence insufficiency | Requires 1 or 2 + 3<br>1. Distance esophoria greater than near esophoria by ≥ 10△<br>2. Distance esophoria greater than near esophoria by ≥ 4△<br>3. Reduced distance NFV (break point ≤ 4△ or failed Sheard's criterion) |
| Basic exophoria | Requires 1, 2, and at least 1 sign from 3 ~ 5<br>1. Difference between near and distance exophoria ≤ 3△<br>2. Subjects need to be exophoria at both distant and near<br>3. PFV at far ≤ 4 /10/ 5△ and ≤ 11/14/3 △ at near (at least one of three)<br>4. NPC break point ≥ 6 cm<br>5. Near VF ≤ 12 cpm |
| Basic esophoria | Requires 1 and 2 and at least 1 sign from 3 ~ 4<br>1. Difference between near and distance esophoria ≤ 3△<br>2. Subjects need to be esophoria at both distance and near<br>3. NFV at far ≤ X/3/1 △ and ≤ 8/16/7 △ at near (at least one of three)<br>4. Near VF ≤ 12 cpm |
| Fusional vergence dysfunction | Requires 1, 2, and at least 1 sign from 3 ~ 4<br>1. No significant phoria at distance and near (distance: exophoria ≤ 2△ to orthophoria; near: exophoria ≤ 5△ to orthophoria)<br>2. No other vergence dysfunction diagnosed<br>3. Reduced NFV or PFV (PFV break point ≤ 15△ or NFV break point ≤ 7△ or failed Sheard's criterion)<br>4. Near VF ≤ 12 cpm |
| Accommodative insufficiency | Requires 1<br>1.Monocular AA at least 2 D below minimum age-based norms as defined by Hofstetter's formula (15-age/4) |
| Accommodative infacility | (Requires 1 or 2<br>1.MAF ≤ 6 cpm with ± 2.00 D lenses<br>2.BAF ≤ 3 cpm with ± 2.00 D lenses |

*NPC*, near point of convergence; *PFV*, positive fusional vergence; *NFV*, negative fusional vergence; *cpm*, cycle per minute; *AA*, amplitude of accommodation; *BAF*, binocular accommodative facility; *MAF*, monocular accommodative facility; *VF*, vergence facility

advertisement. All examinations were performed at West China Hospital of Sichuan University from March 2021 to May 2022. The inclusion criteria for participants were as follows: (1) aged 18 to 35 years, (2) unremarkable general and ocular health, and (3) best-corrected visual acuity of at least 0.8 (< 0.1 logMAR) in each eye. The exclusion criteria were as follows: (1) the presence of strabismus or a history of intraocular surgery, (2) the absence of binocular vision or anterior segment pathological conditions, and (3) severe brain injury and any diagnosed neurological diseases or psychiatric disorders. The CISS, refractive examinations, and accommodative and binocular tests were administered to all participants.

Each dysfunction was diagnosed by an optometrist using methods described in our previous study (Table 1) [12]. The participants who had an overall CISS score ≥ 21 and clinical signs were classified as symptomatic participants and included in the frequency study. The participants who had normal findings and an overall CISS score < 21 were classified as having NBV. Thus, recruited participants were classified into three groups according to the diagnostic criteria: ADs, BDs, and NBV groups.

## CISS

Before the accommodative and binocular tests, symptoms were examined using the validated CISS [5, 6], which was translated into Chinese based on the Brislin translation model [13]. In the CISS, participants are instructed to rate the presence of any symptoms on a five-point Likert scale. For example, on the item "Do your eyes feel tired when reading or doing close work?", participants selected their answer from five possible options

(from never as 0 to always as 4). The points on these 15 items were summed to obtain the CISS total score, which ranged from 0 to 60 points. The total score and the score on each item of the CISS were used for further analyses.

### Refractive, accommodative, and binocular tests

All participants underwent an optometric examination by two optometrists (Y.W. and L.X.). The refractive examination was performed using static retinoscopy and subjective refraction (Nidek RT-600, Japan). The accommodative and binocular tests included the following assessments: direction and magnitude of horizontal and vertical phoria, accommodative convergence/accommodation ratios, positive and negative fusional vergence, positive and negative relative accommodation, near point of convergence, accommodative facility, vergence facility, and accommodative amplitude. Details about this battery of tests have been described in our previous publication [12].

### Statistical analysis

All statistical analyses were performed using SPSS 23.0. Cronbach's alpha coefficient was calculated and a principal component analysis was performed to determine the reliability and validity of the CISS. A 1-to-1 propensity score matching (PSM) method was used to overcome the large differences in sample sizes between three groups. The variables selected to calculate the PSM included sex and spherical equivalent refraction with a caliper of 0.3. Two separate PSMs were conducted for ADs vs. NBV and BDs vs. NBV.

After PSM, Mann−Whitney *U* test was used to compare CISS scores of the NBV group with the ADs group and the BDs group. We did not use any correction for multiple comparisons because this study was exploratory and tried to find relevant information and suggestions for further research [14]. Pearson's correlation analysis was performed to investigate the correlations between symptoms and clinical findings. $P<0.05$ was considered significant for all abovementioned analyses.

## Results

### Participant characteristics

Of the 241 consecutive patients who visited our optometry clinic during the study period, six were excluded from the analyses due to the presence of strabismus ($n=3$) and amblyopia ($n=3$). Therefore, the final number of participants included in this study was 235. The mean age was $23.7\pm2.9$ years, and 73 (31.1%) were male. Of these, 40 patients were in the ADs group, 77 patients were diagnosed with BDs, and 118 participants were in the NBV group. After PSM, no significant differences in the sex ratio, or spherical equivalent refraction were observed between the ADs group and the NBV group or between the BDs group and the NBV group (Table 2).

### Frequency of ADs and/or BDs

In the total sample, the number (frequency) of individuals with ADs and/or BDs was 117 (49.8%). Specifically, 40 patients (17%) had ADs, and 77 patients (32.8%) had BDs. The most prevalent AD was accommodative infacility, with a frequency of 9.8% (23 patients) followed by accommodative insufficiency ($n=17$, 7.2%). The most prevalent BD was CI, with a frequency of 18.7% (44 patients) followed by basic esophoria ($n=16$, 6.8%), convergence excess ($n=12$, 5.1%), and divergence insufficiency ($n=3$, 1.3%). Fusional vergence dysfunction and basic exophoria had the same frequency ($n=1$, 0.4%, respectively). The clinical findings of three groups are shown in Table 3.

**Table 2** Demographic characteristics of three groups before and after propensity score matching

| | ADs group | NBV group | *P* | BDs group | NBV group | *P* |
|---|---|---|---|---|---|---|
| Before propensity score matching | | | | | | |
| Sample size, *n* | 40 | 118 | | 77 | 118 | |
| Age (year) | 24.0 ± 2.8 | 23.5 ± 2.7 | 0.315 | 23.8 ± 3.0 | 23.5 ± 2.7 | 0.559 |
| Male, *n* (%) | 15 (37.5%) | 27 (22.9%) | 0.059 | 31 (40.3%) | 27 (22.9%) | 0.008* |
| Spherical equivalent refraction (D) | − 2.70 ± 1.70 | − 3.31 ± 1.77 | 0.047* | − 3.29 ± 1.55 | − 3.31 ± 1.77 | 0.774 |
| After propensity score matching | | | | | | |
| Sample size, *n* | 40 | 40 | | 77 | 77 | |
| Age (year) | 24.0 ± 2.8 | 23.4 ± 3.2 | 0.245 | 23.8 ± 3.0 | 23.6 ± 3.0 | 0.768 |
| Male, *n* (%) | 15 (37.5%) | 19 (47.5%) | 0.498 | 31 (40.3%) | 26 (33.8%) | 0.505 |
| Spherical equivalent refraction (D) | − 2.70 ± 1.70 | − 3.34 ± 1.55 | 0.087 | − 3.29 ± 1.55 | − 3.40 ± 1.68 | 0.582 |

*ADs*, accommodative dysfunctions; *BDs*, binocular dysfunctions; *NBV*, normal binocular vision; *Statistical significance ($P<0.05$)

**Table 3** The clinical findings of three groups before and after propensity score matching

| | ADs group | NBV group | *P* | BDs group | NBV group | *P* |
|---|---|---|---|---|---|---|
| Before propensity score matching | | | | | | |
| Sample size, *n* | 40 | 118 | | 77 | 118 | |
| AA (right eye, D) | 8.64 ± 1.76 | 10.86 ± 1.66 | < 0.001* | 10.31 ± 1.79 | 10.86 ± 1.66 | 0.045* |
| MAF(right eye, cpm) | 4.86 ± 3.76 | 13.24 ± 2.37 | < 0.001* | 11.82 ± 3.54 | 13.24 ± 2.37 | 0.002* |
| BAF (cpm) | 4.09 ± 3.64 | 13.36 ± 2.36 | < 0.001* | 12.23 ± 3.47 | 13.36 ± 2.36 | 0.018* |
| Phoria (Δ) | | | | | | |
| Near | − 6.54 ± 7.38 | − 1.95 ± 2.97 | < 0.001* | − 5.78 ± 11.02 | − 1.95 ± 2.97 | 0.008* |
| Distance | − 2.38 ± 4.32 | − 1.44 ± 2.09 | 0.093 | − 1.42 ± 5.08 | − 1.44 ± 2.09 | 0.440 |
| PFV (near break point) (Δ) | 19.85 ± 9.28 | 25.51 ± 5.92 | < 0.001* | 19.75 ± 9.70 | 25.51 ± 5.92 | < 0.001* |
| NFV (near break point) (Δ) | 18.37 ± 5.18 | 19.37 ± 5.06 | 0.256 | 20.04 ± 7.35 | 19.37 ± 5.06 | 0.457 |
| NPC break (cm) | 5.50 ± 1.89 | 4.00 ± 0.89 | < 0.001* | 6.90 ± 3.10 | 4.00 ± 0.89 | < 0.001* |
| After propensity score matching | | | | | | |
| Sample size, *n* | 40 | 40 | | 77 | 77 | |
| AA (right eye, D) | 8.64 ± 1.76 | 10.49 ± 1.20 | < 0.001* | 10.31 ± 1.79 | 10.72 ± 1.65 | 0.207 |
| MAF (right eye, cpm) | 4.86 ± 3.76 | 12.94 ± 2.24 | < 0.001* | 11.82 ± 3.54 | 13.16 ± 2.44 | 0.011* |
| BAF (cpm) | 4.09 ± 3.64 | 12.80 ± 2.25 | < 0.001* | 12.23 ± 3.47 | 13.20 ± 2.43 | 0.077 |
| Phoria (Δ) | | | | | | |
| Near | − 6.54 ± 7.38 | − 2.29 ± 2.92 | 0.001* | − 5.78 ± 11.02 | − 2.39 ± 2.70 | 0.020* |
| Distance | − 2.38 ± 4.32 | − 1.25 ± 1.95 | 0.085 | − 1.42 ± 5.08 | − 1.51 ± 2.07 | 0.512 |
| PFV (near break point) (Δ) | 19.85 ± 9.28 | 24.00 ± 5.68 | 0.020* | 19.75 ± 9.70 | 25.28 ± 5.95 | < 0.001* |
| NFV (near break point) (Δ) | 18.38 ± 5.18 | 17.58 ± 4.22 | 0.565 | 20.04 ± 7.35 | 19.05 ± 4.63 | 0.346 |
| NPC break (cm) | 5.50 ± 1.89 | 4.13 ± 1.02 | 0.002* | 6.90 ± 3.10 | 4.16 ± 0.88 | < 0.001* |

*ADs*, accommodative dysfunctions; *BDs*, binocular dysfunctions; *NBV*, normal binocular vision; *AA*, accommodative amplitude; *BAF*, binocular accommodative facility; *MAF*, monocular accommodative facility; *NPC*, near point of convergence; *PFV*, positive fusional vergence; *NFV*, negative fusional vergence; *Statistically significant ($p < 0.05$)

## Comparison of performance-related and eye-related symptoms

Regarding CISS, Cronbach's alpha coefficient of the reliability analysis was 0.89, and the Kaiser−Meyer−Olkin value of validity analysis was 0.80, indicating a high internal consistency and reliability of the questionnaire.

After PSM, the ADs group reported significantly more severe eye-related symptoms of pulling around eyes ($P < 0.05$) than the NBV group, and the BDs group reported significantly more severe eye-related symptoms of words moving and jumping ($P < 0.05$) than the NBV group. Both ADs and BDs groups reported similar significantly more eye-related symptoms (including eyes feeling tired, uncomfortable eyes, eyes hurting, eyes feeling sore, and words blurring; all $P < 0.05$), experienced similar more performance-related symptoms (including feeling sleepy, losing concentration, trouble remembering, reading slowly, losing place, and having to re-read; all $P < 0.05$), and had a significantly higher mean CISS total score ($P < 0.05$) than the NBV group (Table 4).

In addition, a proportion analysis was applied to CISS scores to compare the percentages of adults in three groups who responded to each item with "fairly often" or "always." As shown in Fig. 1, the top five highest-ranked symptoms in the ADs group and BDs group were related to performance-related symptoms, including losing place, losing concentration, reading slowly, trouble remembering, and having to re-read.

## Correlation between symptoms and clinical findings

As shown in Fig. 2, significant correlations were observed of eye-related symptoms, performance-related symptoms, and CISS total score with the clinical findings, including accommodative amplitude ($r = -0.286$, $r = -0.294$, and $r = -0.306$, respectively), binocular accommodative facility ($r = -0.378$, $r = -0.446$, and $r = -0.440$, respectively), near phoria ($r = -0.235$, $r = -0.261$, and $r = -0.263$, respectively), near point of convergence ($r = 0.397$, $r = 0.482$, and $r = 0.470$, respectively), and positive fusional vergence ($r = -0.264$, $r = -0.331$, and $r = -0.319$, respectively) (all $P < 0.001$).

**Table 4** Comparison of CISS total score and each item score among three subgroups before and after propensity score matching

| | ADs group | NBV group | *P* | BDs group | NBV group | *P* |
|---|---|---|---|---|---|---|
| Before propensity score matching | | | | | | |
| Sample size, *n* | 40 | 118 | | 77 | 118 | |
| Eyes feeling tired | 2.75 ± 0.59 | 1.14 ± 0.72 | < 0.001* | 2.88 ± 0.71 | 1.14 ± 0.72 | < 0.001* |
| Uncomfortable eyes | 2.48 ± 0.75 | 1.22 ± 0.72 | < 0.001* | 2.60 ± 0.78 | 1.22 ± 0.72 | < 0.001* |
| Getting headaches | 0.87 ± 0.88 | 0.63 ± 0.64 | 0.158 | 0.86 ± 0.79 | 0.63 ± 0.64 | 0.048* |
| Feeling sleepy | 3.20 ± 0.72 | 0.96 ± 0.70 | < 0.001* | 3.09 ± 0.73 | 0.96 ± 0.70 | < 0.001* |
| Losing concentration | 3.60 ± 0.59 | 0.66 ± 0.71 | < 0.001* | 3.55 ± 0.55 | 0.66 ± 0.71 | < 0.001* |
| Trouble remembering | 3.48 ± 0.60 | 0.78 ± 0.67 | < 0.001* | 3.31 ± 0.59 | 0.78 ± 0.67 | < 0.001* |
| Double vision | 0.75 ± 0.87 | 0.53 ± 0.66 | 0.205 | 0.62 ± 0.73 | 0.53 ± 0.66 | 0.366 |
| Words moving & jumping | 0.83 ± 0.96 | 0.52 ± 0.62 | 0.126 | 1.17 ± 0.94 | 0.52 ± 0.62 | < 0.001* |
| Reading slowly | 3.55 ± 0.60 | 0.69 ± 0.62 | < 0.001* | 3.40 ± 0.59 | 0.69 ± 0.62 | < 0.001* |
| Eyes hurting | 2.35 ± 0.86 | 0.81 ± 0.77 | < 0.001* | 2.42 ± 0.83 | 0.81 ± 0.77 | < 0.001* |
| Eyes feeling sore | 2.70 ± 0.69 | 1.11 ± 0.76 | < 0.001* | 2.60 ± 0.78 | 1.11 ± 0.76 | < 0.001* |
| Pulling around eyes | 2.55 ± 0.88 | 0.97 ± 0.77 | < 0.001* | 1.26 ± 0.97 | 0.97 ± 0.77 | 0.050 |
| Words blurring | 1.45 ± 0.93 | 0.68 ± 0.67 | < 0.001* | 1.30 ± 1.08 | 0.68 ± 0.67 | < 0.001* |
| Losing place | 3.40 ± 0.59 | 0.61 ± 0.67 | < 0.001* | 3.25 ± 0.59 | 0.61 ± 0.67 | < 0.001* |
| Having to re-read | 3.42 ± 0.64 | 0.60 ± 0.68 | < 0.001* | 3.26 ± 0.75 | 0.60 ± 0.68 | < 0.001* |
| CISS total score | 37.38 ± 4.47 | 11.90 ± 5.48 | < 0.001* | 35.56 ± 4.37 | 11.90 ± 5.48 | < 0.001* |
| After propensity score matching | | | | | | |
| Sample size, *n* | 40 | 40 | | 77 | 77 | |
| Eyes feeling tired | 2.75 ± 0.59 | 1.12 ± 0.72 | < 0.001* | 2.88 ± 0.71 | 1.19 ± 0.78 | < 0.001* |
| Uncomfortable eyes | 2.48 ± 0.75 | 1.25 ± 0.81 | < 0.001* | 2.60 ± 0.78 | 1.27 ± 0.76 | < 0.001* |
| Getting headaches | 0.87 ± 0.88 | 0.65 ± 0.62 | 0.328 | 0.86 ± 0.79 | 0.74 ± 0.68 | 0.400 |
| Feeling sleepy | 3.20 ± 0.72 | 0.95 ± 0.78 | < 0.001* | 3.09 ± 0.73 | 1.05 ± 0.74 | < 0.001* |
| Losing concentration | 3.60 ± 0.59 | 0.58 ± 0.68 | < 0.001* | 3.55 ± 0.55 | 0.70 ± 0.73 | < 0.001* |
| Trouble remembering | 3.48 ± 0.60 | 0.85 ± 0.66 | < 0.001* | 3.31 ± 0.59 | 0.79 ± 0.66 | < 0.001* |
| Double vision | 0.75 ± 0.87 | 0.48 ± 0.55 | 0.234 | 0.62 ± 0.73 | 0.49 ± 0.58 | 0.368 |
| Words moving and jumping | 0.83 ± 0.96 | 0.52 ± 0.68 | 0.208 | 1.17 ± 0.94 | 0.61 ± 0.67 | < 0.001* |
| Reading slowly | 3.55 ± 0.60 | 0.70 ± 0.56 | < 0.001* | 3.40 ± 0.59 | 0.69 ± 0.59 | < 0.001* |
| Eyes hurting | 2.35 ± 0.86 | 0.75 ± 0.74 | < 0.001* | 2.42 ± 0.83 | 0.82 ± 0.74 | < 0.001* |
| Eyes feeling sore | 2.70 ± 0.69 | 1.00 ± 0.78 | < 0.001* | 2.60 ± 0.78 | 1.10 ± 0.79 | < 0.001* |
| Pulling around eyes | 2.55 ± 0.88 | 0.95 ± 0.71 | < 0.001* | 1.26 ± 0.97 | 1.03 ± 0.79 | 0.172 |
| Words blurring | 1.45 ± 0.93 | 0.55 ± 0.55 | < 0.001* | 1.30 ± 1.08 | 0.73 ± 0.68 | 0.001* |
| Losing place | 3.40 ± 0.59 | 0.53 ± 0.60 | < 0.001* | 3.25 ± 0.59 | 0.60 ± 0.59 | < 0.001* |
| Having to re-read | 3.42 ± 0.64 | 0.57 ± 0.64 | < 0.001* | 3.26 ± 0.75 | 0.60 ± 0.63 | < 0.001* |
| CISS total score | 37.38 ± 4.47 | 11.45 ± 5.80 | < 0.001* | 35.56 ± 4.37 | 12.42 ± 5.35 | < 0.001* |

*ADs*, accommodative dysfunctions; *BDs*, binocular dysfunctions; *NBV*, normal binocular vision; *CISS*, convergence insufficiency symptom survey questionnaire; *Statistically significant ($p < 0.05$)

## Discussion

As expected, ADs and/or BDs are commonly present in Chinese adults treated at optometric clinics, and adults diagnosed with ADs and/or BDs exhibit more performance-related symptoms than participants with NBV. In addition, the five most frequently reported visual symptoms by adults with ADs and/or BDs were all performance-related items.

### Frequency of ADs and BDs

This present study obtained a much higher frequency of ADs and/or BDs than our previous study [12], which examined 99 emmetropic civilian pilots younger than 35 years of age with or without visual symptoms, and found that 15 (15.2%%) presented some type of AD or BD. Although both studies recruited participants of the same ethnicity and performed similar measurement methods and

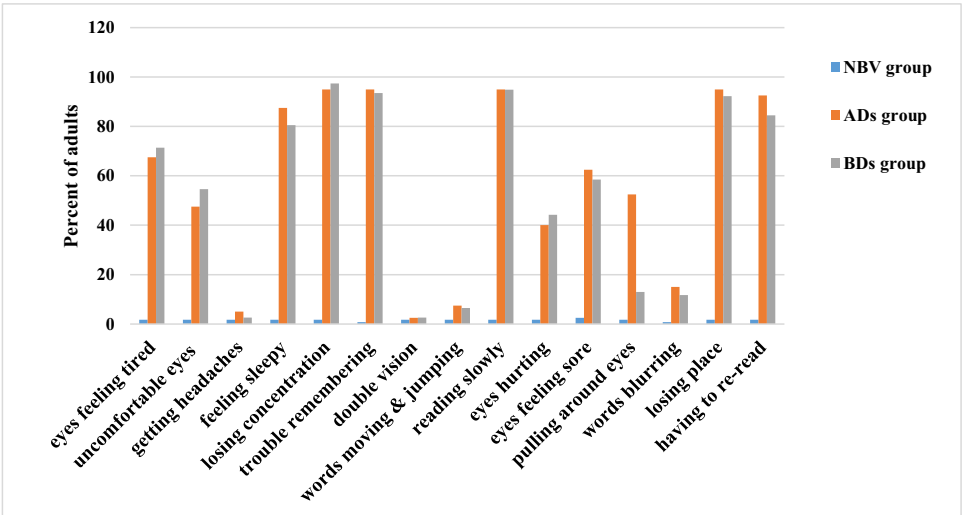


**Fig. 1** Frequency distribution of symptoms that subjects reported experiencing "fairly often" or "always" on the Convergence Insufficiency Symptom Survey (CISS) among the normal binocular vision (NBV) group, accommodative dysfunctions (ADs) group, and binocular dysfunctions (BDs) group

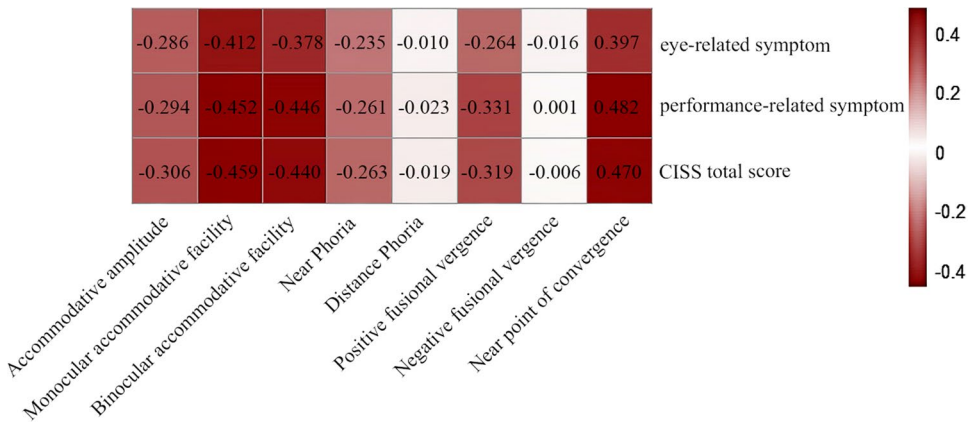


**Fig. 2** Pearson correlations between clinical findings and visual symptoms. The rows correspond to visual symptoms, and the columns correspond to clinical findings. Each cell contains the corresponding correlation coefficient (*r*). The color scheme represents the strength of the correlation (in terms of the correlation coefficient; *r*)

diagnostic criteria, they were not strictly comparable. The samples from this study were derived from a clinical population seeking solutions to visual symptoms, which might have contributed to the higher frequency of visual dysfunction than in the civilian pilot sample. Martin et al. [10] examined the frequency of ADs and/or BDs in a clinical population of 415 Chinese participants and found that 178 patients (42.9%) in the total sample had general binocular disorders, which is fairly consistent with the findings of the present study, as both studies used the same clinical populations and similar diagnostic criteria. Therefore, because the presence of ADs and/or BDs might cause misdiagnosis, diagnostic confusion, or exacerbation of attention deficits, the high frequency of adults with ADs and/or BDs found by the present study might provide preliminary evidence to emphasize the importance of a comprehensive vision evaluation to assess the presence of ADs and/or BDs beyond a typical vision screen in clinical practice for adults who present with visual symptoms.

## Severe performance-related symptoms of adults with ADs and/or BDs

Since many studies have investigated whether patients with ADs and/or BDs have much more significant eye-related symptoms than participants with NBV [15, 16], little is known about the performance-related symptoms among adult patients with ADs and/or BDs; thus, subsequent discussions pertain only to those items. In the current study, adults with ADs and/or BDs reported a higher frequency and a much more severe degree of performance-related symptoms (e.g., losing concentration and trouble remembering) than participants with NBV, which are similar to behaviors associated with attention deficits, such as "often has trouble sustaining attention during tasks or play activities" and "often forgetful performing daily activities" [9, 17]. Previous studies have found that children with symptomatic convergence insufficiency reported performance-related symptoms more frequently than eye-related

symptoms [7, 8]. Notably, our study found that not only adults with convergence insufficiency but also adults with ADs and/or BDs other than convergence insufficiency more frequently reported performance-related symptoms than those with NBV. Due to the mutual interactions between accommodation and vergence systems, a deficiency in one system might cause an abnormality in the other such that visual symptoms would overlap. Scientific studies have shown that visual-related symptoms are very similar in patients with ADs and/or BDs [18]. Therefore, the finding that performance-related symptoms were related to both ADs and BDs in the present study might provide further insight into the symptomatic mechanism of the pathophysiology of ADs and BDs.

The symptoms "losing place" and "having to re-read" might originate from either oculomotor/tracking dysfunction or a deficiency in higher-order visual attention processing or even cognitive processing. The symptom "losing concentration" might fall into this latter category [19]. One intriguing possible explanation relates to the utilization of executive function. Executive functioning is the higher-order cognitive process that enables individuals to organize, plan, pay attention, and manage time and space [20]. If individuals present visual deficits, such as vergence deficits, they might use more of their executive functioning to compensate for their visual dysfunctions, leaving less attention in reserve to maintain an attentional state [9, 21]. This theory is supported by the findings that a greater possibility of presenting attentional deficits or a more severe degree of attentional deficits occurs in participants with vision deficits, such as amblyopia [22] and nystagmus [19]. Furthermore, this theory is also confirmed by the fact that if visual dysfunctions such as convergence insufficiency or accommodative-vergence mismatch are treated, academic behaviors associated with reading and school work might be enhanced [23].

Additionally, previous studies have found that the oculomotor neural substrates used to mediate a vergence response overlap with parts of the visual attention network. For example, a recent study provided physiological evidence that frontoparietal areas might be dysfunctional in children with attentional deficits [24]. Alvarez et al. [25] found that patients with convergence insufficiency showed significantly less functional activity and task-modulated coactivation in frontoparietal areas than controls. Frontoparietal areas are involved in controlling near response and in the association of accommodation, convergence, and visual fixation [26]; it is also a structure that is linked to distractibility and top-down attention [27]. Perhaps, since neural substrates are shared, particularly within the frontoparietal areas, patients with ADs and/or BDs might be more prone to performance-related symptoms.

## Correlations between performance-related symptoms and clinical findings

This study also found significant correlations between visual symptoms and clinical findings. Recent studies reported significant associations between defective clinical measures and visual symptoms, consistent with the present study [6], which suggests that adults with deficits in clinical findings are more likely to manifest severe visual symptoms than those with normal ranges of these parameters. Therefore, the presence of ADs and/or BDs might contribute to adults' symptom complaints, such as "losing concentration" and "trouble remembering," which might be considered risk factors for lower reading performance and attention and inability to concentrate for long periods during near visual work that might reduce the level of an individual's achievement [7]. Thus, adults presenting with significant symptoms, especially performance-related symptoms, might need a comprehensive vision evaluation to assess the presence of ADs and/or BDs. Nevertheless, our data do not allow us to definitively determine the causal directionality between ADs and/or BDs and performance-related symptoms. Therefore, more studies of the relationship between ADs and/or BDs and performance-related symptoms and their potential effects on reading performance and attention are warranted in the future.

## Limitations

This study has some limitations. First, it should be noted that this study is not a prevalence study due to its clinic-based nature. Participants who were willing to participate may have had more visual symptoms through advertisement and might have provided an overestimation of ADs and/or BDs. Thus, the frequency finding of this study can only be considered as estimations of the studied populations and cannot be extrapolated to the general population. Second, the number of female participants was much larger than that of male participants. Most previous studies have suggested that sex was not a significant confounding factor in the association between ADs and/or BDs and visual symptoms [18]. Thus, the large sex imbalance might not have led to a bias in the statistical analyses and results. Third, the ADs group had a relatively small sample size in the present study. The NBV group (1:1 ratio) was selected using PSM to overcome the limitations of large differences in sample sizes among the three groups, which might overcome the possibility of selection bias to some extent. Last, participants included in this study were diagnosed with performance-related symptoms entirely based on CISS, and we did not confirm that a diagnosis had been made by a qualified clinical psychologist or psychiatrist. However, the reliable and valid symptom checklist is a quick, easy, and cost-effective method to collect meaningful data, which might be a helpful adjunct to indicate to optometrists and ophthalmologists what aspect

of the visual system may be affected while requiring further psychological or psychiatric evaluations. Further, since previous studies have found convergence insufficiency would affect brain functional activation [25], multimodal brain MRI methods could provide new insights into brain structural and functional alterations [28–30] underlying neuromechanism in ADs and BDs for future studies [31].

## Conclusions

The present study suggests that ADs and/or BDs are commonly present in Chinese adults treated at optometric clinics, and adults diagnosed with ADs and/or BDs exhibit more performance-related symptoms than participants with NBV, which might cause misdiagnosis, diagnostic confusion, or exacerbation of attention deficits. Thus, this study might provide preliminary evidence to emphasize the importance of a comprehensive vision evaluation to assess the presence of ADs and/or BDs beyond a typical vision screen in clinical practice for adults who present with significant visual symptoms, especially performance-related symptoms.

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## Declarations

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of West China Hospital of Sichuan University (No 2021 (268), 15–3-2021) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all participants included in the study.

**Conflict of interest** All authors declare no competing interests.

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