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ORIGINAL ARTICLE

Accommodative Insufficiency Is the Primary Source of Symptoms in Children Diagnosed With Convergence Insufficiency

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ABSTRACT

Purpose. Accommodative insufficiency (AI) and convergence insufficiency (CI) have been associated with similar symptomology and frequently present at the same time. The severity of symptomology in CI has been linked to the severity of the CI, suggesting a dose-dependent relationship. However, with increasing severity of CI also comes increased comorbidity of AI. AI alone has been shown to cause significant symptomology. We hypothesize that AI drives the symptoms in CI with a comorbid AI condition (CIwAI) and that it is the increased coincidence of AI, rather than increased severity of CI, which causes additional symptomology.

Methods. Elementary school children (n = 299) participated in a vision screening that included tests for CI and AI and the CISS-V15 symptom survey. They were categorized into four groups:1) normal binocular vision (NBV); 2) AI-only; 3) CI-only; and 4) CIwAI. One hundred seventy elementary school children fell into the categories of interest.

Results. Pairwise comparison of the group means on the symptom survey showed: 1) children with AI-only (mean = 19.7, $p = 0.006$) and children with CIwAI (mean = 22.8, $p = 0.001$) had significantly higher symptom scores than children with NBV (mean = 10.3); and 2) children with CI-only (mean = 12.9, $p = 0.54$) had a similar symptom score to children with NBV. Using a two-factor analysis of variance (AI and CI), the AI effect was significant (AI mean = 21.56; no AI mean = 11.56, $p < 0.001$), whereas neither the CI effect ($p = 0.16$) nor the CI by AI interaction effect ($p = 0.66$) were significant.

Conclusion. CI is a separate and unique clinical condition and can occur without a comorbid AI condition, our CI-only group. Past reports of high symptom scores for children with CI are the result of the presence of AI, a common comorbid condition. When AI is factored out, and children with CI only are evaluated, they are not significantly more symptomatic than children with NBV.

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Key Words: convergence insufficiency, accommodative insufficiency, symptoms, eyestrain, children

Accommodative insufficiency (AI) is a sensory motor anomaly of the visual system that is characterized by an inability to focus or sustain focus at near, demonstrated clinically by an insufficient amplitude of accommodation based on age-expected norms.[1,2] Convergence insufficiency (CI) is a sensory motor anomaly that is characterized by an inability to accurately converge or sustain convergence at near, defined clinically by exophoria at near, a more exophoric tonic position at near than at far, a remote near point of convergence, and decreased fusional amplitudes.[3,4]

Accommodation and convergence are coupled physiologically. Through this coupling, when the eyes accommodate, they also converge, accommodative convergence, quantified by the AC/A ratio, and when the eyes converge, they also accommodate, convergence accommodation, quantified by the C/AC ratio.[5,6]

AI and CI frequently present at the same time clinically[7–9] possibly as a result of this neurologic coupling. The rate of the comorbidity has been shown to increase with the severity of the CI. In two population-based studies, the comorbidity of AI with clinically significant CI ranged from 37.5% and 26% for CI with two signs, CI-2, and a comorbidity of 78% and 79% in children with all three signs of CI, CI-3.[10,11] (See our "Data Analysis" section under "Methods" for detailed descriptions of these categories.)

AI and CI have also been associated with similar symptomatology. In a retrospective review of 96 patients diagnosed with AI, Daum[12] reported a high incidence of blur (59%), headache (56%), asthenopia (45%), and diplopia (30%). In another study by Daum,[13] a retrospective review of patients diagnosed with *symptomatic* CI, patients reported the same symptoms in similar frequency: blur (47%), headaches (54%), asthenopia (36%), and diplopia (47%). A limitation of Daum's studies is that the clinical profile of the patients in each study shows considerable overlap: 65% of the patients in the AI study have CI, and the mean amplitude of accommodation in the CI study does not meet Hofstetter's minimum amplitude.

Borsting[11] provided a more quantitative analysis of the prevalence and severity of symptoms known to occur both in patients with AI and patients with CI. Using the CISS symptom survey of 16 questions and a 3-point scale ranking system for frequency of occurrence, Borsting administered this survey to 392 school children aged 8 to 15 years. He then identified the participants' binocular status and compared the symptom survey scores across groups. The groups included: normal binocular vision (NBV), AI only, and two levels of clinically significant CI: CI-2 and CI-3. (See our "Data Analysis" section under "Methods" for detailed descriptions of these categories.)

Compared with children with NBV, symptom scores were significantly higher in children with AI only and children with CI-3 but not in children with CI-2. In fact, children with CI-2 had a mean symptom score similar to the NBV group (3.78 for NBV, 4.7 for CI-2), whereas the CI-3 score was similar to the AI only score (6.7 for CI-3, 6.34 for AI only). Although Borsting quantified the difference in prevalence of comorbid AI in the CI-2 and CI-3 groups, he did not differentiate CI with or without comorbid AI in assessing the symptom score. Of note, 79% of the children with CI-3 had AI, whereas only 26% of children with CI-2 had AI.

Because the singular presence of AI can result in a high symptom score, as seen in the AI only children's score, we hypothesized that the high prevalence of comorbidity of AI in the CI-3 group may be the reason for the high symptom score in this group. This would argue against the hypothesis that it is the severity of the CI that is at the root of higher symptoms in CI-3 compared with CI-2, negating the hypothesis of a dose-dependent relationship of symptoms to severity of CI that was suggested in a clinical review of convergence insufficiency.[14]

The overlap of the *type* of symptoms in AI and CI that have been reported by Daum[12,13] and Borsting[11] may also be an artifact of the comorbidity of the conditions and the failure to isolate each condition when evaluating symptoms.

To test these hypotheses, we conducted a similar study to Borsting's population study[11] and evaluated the independent effects of AI and CI on the symptom score by comparing scores across four main groups: NBV, CI-only (no comorbid AI), AI-only, and CI with comorbid AI (CIwAI).

We further evaluated the response distributions of the individual questions of the survey, across the four groups, to provide a better clinical symptom profile of each clinical condition.

METHODS

Study Population

Fourth, fifth, and sixth grade children from 19 elementary schools in Fullerton, California, were recruited for the study. Parental and child informed consent were obtained for each child who participated in the study. The study was described as extra testing after the regular school screening, which would include tests to evaluate a child's vision for near-work tasks. The study was approved by Southern California College of Optometry's Institutional Review Board for Human Subjects and the superintendents of the schools. Tenets of the Declaration of Helsinki were followed.

Procedure

The CISS-V15 symptom survey[15] (see Appendix for list of survey questions; available online at www.optvissci.com) and the informed consent documents (ICDs) were sent out to the children's parents or guardians by the participating schools. Children were instructed to self-complete the survey. Completed surveys and ICDs were required before any vision testing was conducted. Examiners were blind to the survey responses. All vision screening tests were administered at the child's school during regular school hours between 8 AM and 12 PM.

Eligibility

Testing began with retinoscopy and visual acuity testing at 20 feet. Children with visual acuity worse than 20/30 in either eye, hyperopia $\geq$1.50 D, astigmatism $\geq$1.00D, and anisometropia $\geq$1.0 D were excluded from further testing.

Binocular Vision, Accommodation, and Eye Movement Tests

The following tests were performed in random order on the remaining children. Monocular accommodative amplitude, of the right eye only, was measured by Donder's Pushup method using a single 20/30 reduced Snellen line target and the Astron International Accommodative Rule. Von Graefe heterophoria measurements were made with prism neutralization at testing distances of 6 m (far) and 40 cm (near) using a single 20/30 Snellen letter target. Positive fusional vergence (PFV) and negative fusional vergence (NFV) ranges (blur/break and recovery) were conducted at near (40 cm) with a horizontal prism bar and a reduced 20/30 Snellen letter target. The near point of convergence (NPC) break was determined by bringing a single 20/30 Snellen letter target on a 6-mm fixation ball from a 40-cm distance until the subject reported diplopia or the examiner observed a loss of binocular fixation. The subject was encouraged to try to keep the target single. Distance to breakpoint was calculated from the midsagittal plane of the patient's head to the nearest half centimeter. Binocular accommodative facility was measured using polarized lenses, $\pm$2.00-D flippers and the 20/30 letter line on Vectogram 9 (Bernell), which includes a suppression check for the binocular testing. Monocular accommodative facility was measured in the same manner without polarized glasses and with the nonviewing left eye occluded.[16] The Developmental Eye Movement Test (DEM) was performed at a remote distance from the other tests to minimize ambient noise.[17] The tests results for monocular accommodative amplitude, near and far phorias, the PFV, and the NPC were used to categorize subjects into the four groups of interest: NBV, CI-only (no comorbid AI), AI-only, and CI with comorbid AI (CIwAI). Test result criteria for classification into these groups is described subsequently.

Data Analysis
Classification

In keeping with the recognized need to standardize CI and AI classification and to facilitate comparative and meaningful research, we adopted the CI classification system used by the Convergence Insufficiency Treatment Trial (CITT) Group.[11,14] We also used the CISS-V15 symptom survey,[15] which is the most recent edition of the CIRS survey.[18]

To evaluate the independent effects of AI and CI on symptoms, children were classified into the following groups (described in detail subsequently): NBV, AI-only, CI-only, CIwAI, and "other" (not falling into the first four categories) using published norms of Morgan,[19] Sheard,[20] and the CITT Group.[11,14] For the main analysis, children with two-sign CI (CI-2) or three-sign CI (CI-3), as described subsequently, were grouped together and classified as CI because these are the levels that are considered clinically significant.[11] In the secondary analysis in which interaction effects of AI and CI were investigated, all three levels of CI (CI-1, CI-2, and CI-3) were evaluated.

Convergence Insufficiency

The three levels of CI classification created by the CITT group were used.[11,14] By this system, a child must meet the criteria of a CI-1 before further CI classification. Once this is met, each additional clinical sign adds to the severity of the CI condition, e.g., CI-2 and CI-3.

Convergence Insufficiency With One Sign

CI-1 is defined as having exophoria at near, and a greater exophoria at near than at far, by at least 4 prism diopters.

Convergence Insufficiency With Two Clinical Signs and Convergence Insufficiency With Three Clinical Signs

CI-1 with one *additional* clinical sign, for a total of two signs, is categorized as CI-2. CI-1 with two additional clinical signs, for a total of three signs, is categorized as CI-3. Additional clinical signs include: 1) insufficient PFV by either failure to reach Sheard's criteria[20] *or* failure to demonstrate minimum normative PFV at near, $\leq$15 for break[16,19] and; 2) receded near point of convergence, $\geq$6 cm break.[21]

Accommodative Insufficiency

AI is defined as having an amplitude of accommodation at least 2 D below Hofstetter's age-based norms (monocular amplitude $\leq$(15-0.25[age]-2),[22,23] on the Donder's monocular pushup test.

Four Clinical Categories of Interest

Normal Binocular Vision

A child must have *all* of the following to be classified in the NBV group: a near phoria between 0 and 6 prism diopters of exophoria and a far phoria between 0 and 2 prism diopters of exophoria with a difference between near and far phoria of $<$4 prism diopters.[19] Sheard's criteria must be met, that is, the positive fusional vergence blur or break point at near must be at least two times the near phoria.[20] The NPC must be equal to or more proximal than 6 cm[21] and Hofstetter's normative accommodation must be met (monocular amplitude: $>$15–0.25(age).[22,24]

Accommodative Insufficiency Only

AI-only is a child with AI who does not have convergence insufficiency.

Convergence Insufficiency Only

CI-only is a child with either CI-2 or CI-3 who does *not* have AI.

Convergence Insufficiency With Comorbid Accommodative Insufficiency

CIwAI is a child with CI-2 or CI-3 who *does* have AI.

RESULTS
Study Population

Four hundred twelve children participated in the first stage of the study, visual acuity, and refractive error screening. Twenty-seven percent of these children failed the visual acuity or refractive error criteria (described previously), leaving 299 children to be evaluated on binocular vision and accommodative status.

One hundred seventy children of these 299 fell into one of the four clinical categories of interest, described previously. The average age of this group was 11.5 years (standard deviation = 0.63). There were no age differences between the four clinical groups (one-way analysis of variance [ANOVA], $p = 0.63$). Prevalence by clinical category in the evaluated sample ($n = 299$) was as follows: NBV 34.3%, AI-only 4.7%, CI-only 14.7%, and CIwAI 3.3%. Mean values and standard deviations for the binocular vision and accommodation tests and the symptom survey scores for each group are shown in Table 1.

Ethnicity

The ethnic makeup of the 412 screened children was 33% Caucasian, 27% Hispanic, 23% Asian, 1.7% African American, and 1.5% Indian. The remaining ethnicities each comprised $<$1% of the total and so were grouped together, representing 12.4% of the total sample. The ethnic makeup of the 299 children who passed the visual acuity and refractive error portion of the screening was virtually identical to the original group of 412 screened. This was also true of the 170 children who fell into one of the four clinical categories of interest (homogeneity test, $p = 0.682$).

We performed a one-way ANOVA test on the total symptom score for the visually normal NBV group of children to see if there was any propensity for higher reporting of symptoms by any ethnic group and found that there was none. ($F = 1.51$, $p = 0.216$). We chose the NBV group for this analysis, because the criteria that defines them would make them the most homogenous group for binocular and accommodative status and hence also the most homogenous for vision-related symptoms.

Gender

Percentage of males and females was 46.1% and 53.9%, respectively, in the four clinical group samples. This makeup was similar to all children screened and to children who passed the visual acuity

TABLE 1.
Mean (± standard deviation) test results for the Binocular Vision tests, the Accommodative Amplitude test and the CISS-V15 symptom survey for the four clinical groups

Test	NBV (n = 102)	CI only (n = 44)	AI only (n = 14)	CIwAI (n = 10)
Heterophoria (− indicates exophoria)				
Phoria at far (Δ)	−0.15 (0.53)	−1.21 (3.44)	−0.43 (1.16)	−1.40 (3.13)
Phoria at near (Δ)	−0.70 (1.10)	−6.84 (3.96)	−0.43 (1.79)	−6.60 (2.99)
Near-Far Phoria (Δ)	−0.55 (0.91)	−5.63 (2.34)	0.00 (1.36)	−5.20 (1.40)
Accom Amp (cm)	4.93 (1.85)	5.43 (2.11)	12.89 (3.78)	13.10 (2.73)
NPC Break (cm)	2.031 (2.08)	6.174 (4.14)	6.00 (6.10)	13.25 (9.38)
PFV				
Break (Δ)	25.34 (10.93)	16.42 (9.38)	20.50 (9.89)	12.60 (4.62)
Recovery (Δ)	18.78 (10.40)	11.74 (8.60)	14.38 (7.83)	7.80 (4.47)
NFV				
Break (Δ)	11.51 (3.89)	12.84 (3.44)	9.71 (3.02)	9.60 (3.86)
Recovery (Δ)	7.30 (3.14)	8.98 (3.33)	6.00 (1.92)	4.80 (3.52)
Symptom Score	10.30 (8.21)	12.88 (10.62)	19.69 (12.72)	22.80 (12.74)

and refractive error screening (homogeneity test, $p = 0.662$). There was a trend for females to be more highly represented in the AI-only group, representing 78.6% of that group, although this did not reach significance ($p = 0.07$). Because the AI-only group was highly symptomatic, and more dominated by females, we tested if there was a propensity for a higher reporting of symptoms in females vs. males. We conducted a two-sample t-test comparing the total symptom scores by gender in the normal binocular vision group; there were no differences in those scores ($x = 10.72$, $x = 9.72$, female, male, respectively, $p = 0.26$).

Uncategorized Children

Although 299 children underwent binocular and accommodative testing, as described previously, only 170 met the defined clinical groups of interest in this research study. The 129 children who did not fall into one of the four clinical categories were classified as "other." Ninety of these children were classified into well-defined clinical conditions[4,11] with a prevalence (n = 299) as follows: CI-1 (10.4%), basic esophoria (2%), basic exophoria (1%), convergence excess (5%), divergence excess (1%), and basic orthophoria with restricted zones who were not already categorized as CI-1 (9%). The remaining 39 children did not fit into *any* clinical category. They failed one or more criteria of our NBV category: 38 failed either the near or far phoria, 12 failed the NPC, and 3 failed Hofstetter's normative accommodative amplitude.

Symptom Survey Score

We tested the hypothesis that a comorbid AI condition drives symptomology in children classified as *symptomatic* CI. A one-way ANOVA of the four clinical group symptom survey means gave significance ($F[3,157] = 7.99$, $p < 0.001$). Pairwise comparisons of the symptom survey mean scores across the groups, using the Tukey procedure, showed that clinically significant CI-only children did not score significantly different than the children with NBV ($x = 12.9$, $x = 10.3$; CI-only, NBV, respectively, $p = 0.54$) unless they have a comorbid AI condition, CIwAI ($x = 22.8$, $p = 0.001$). In contrast, the AI-only children scored significantly higher than the children with NBV ($x = 19.7$, $x = 10.3$, AI-only, NBV, respectively, $p = 0.006$). Furthermore, the AI-only symptom score was not much different than the CIwAI score ($x = 19.7$ and $x = 22.8$, respectively). Mean symptoms scores for each group are illustrated in Figure 1.

The effects of AI and CI on the total symptom score are independent and additive (see Fig. 2). Using a two-factor ANOVA (AI and CI), the AI effect was significant (AI = 21.56; no AI = 11.56, $p < 0.001$), whereas neither the CI effect ($p = 0.16$) nor the CI by AI interaction effect ($p = 0.66$) was significant. Using the Tukey procedure, the comparison of the CI-only and the CIwAI group means was also significant ($p = 0.003$)

Specific Symptoms

The Kruskal-Wallis test was used to determine which of the 15 symptom survey questions (see the Appendix; available at www.optvissci.com) best distinguished between the four clinical groups. Using this nonparametric one-way ANOVA by ranks technique, the null hypothesis that the four groups have the same response distribution was rejected for four of the 15 questions ($p \leq 0.003$, adjusted for multiple tests). The four questions cover the following symptoms: trouble remembering, sore eyes, lose place, and reread. For two additional symptoms, double vision and words blur, marginally significant results ($p \leq 0$ 0.006) were obtained.

The Mann-Whitney test was then conducted on these six symptom questions. The AI-only group and the CIwAI group each

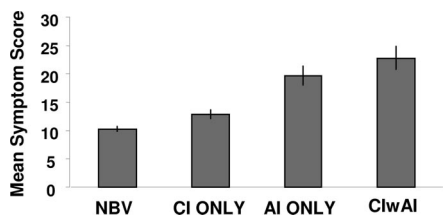

FIGURE 1.
Mean symptom scores, and standard error bars, of the four groups: normal binocular vision, convergence insufficiency only, accommodative insufficiency only, and convergence insufficiency comorbid with accommodative insufficiency.

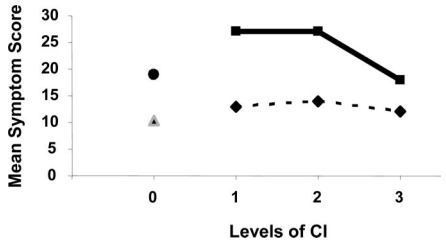

FIGURE 2.

Mean symptom score by level of convergence insufficiency (CI). Dashed line represents the CI-only group (CI-1, CI-2, and CI-3). Solid line represents the convergence insufficiency comorbid with accommodative insufficiency (CIwAI) group (CI-1wAI, CI-2wAI, CI-3wAI). The circle symbol represents the accommodative insufficiency-only group. The triangle symbol represents the group with normal binocular vision.

scored significantly higher than NBV on four of the six questions ($p < 0.008$, adjusted for multiple tests), whereas the CI-only group did not score higher than NBV on any symptom question.

Survey responses were further analyzed using proportion analysis to compare the percentages of children responding to each question at a level of "sometimes, very often, or always" in the three groups compared with the NBV group (see Fig. 3). The AI-only group scored significantly higher than NBV in this secondary analysis ($p < 0.008$, adjusted for multiple tests) on four of the six questions, the CIwAI group on three of the six questions, and the CI-only group on one of the six questions.

The symptom questions that were significantly higher than NBV on both the Mann-Whitney test and on the proportion analysis test were: for the AI-only group, sore eyes, reread, double vision, and words blur, and for the CIwAI group, sore eyes, lose place, and trouble remembering. The CI-only group scored significantly higher on the symptom "lose place" on the proportion analysis, but this significant result was not seen in the original nonparametric Mann-Whitney analysis ($p = 0.03$).

DISCUSSION

This is the first study to differentiate CI-only from CIwAI despite the high comorbidity of the two conditions. The results of this differentiation are important to both the scientific and clinical community.

Pseudo-Convergence Insufficiency?

Our results suggest that CI exists as a condition by itself, contrary to Jampolsky's theory that "all anomalies of convergence can be considered anomalies of *accommodation*, with consequent over- or under-stimulation of accommodative–convergence."[25] This theory would predict that CI results from understimulation of convergence through reduced input from the accommodative–convergence link. By making the differentiation between CI-only and CIwAI, we have shown that the vergence anomalies associated with CI can occur *without* a comorbid AI condition.

Symptomology in CI Similar to Symptomology in AI?

The distinction made in this study between CI only and CIwAI demonstrates that the symptomology previously associated with CI,[10–15,18,26,27] and which was reported to be similar to the symptomology in AI,[11–13] may be an artifact of a comorbid AI condition.

An Improved Understanding of the Comorbid CIwAI Condition Is Needed

One result of this research is that it demonstrates that CI can occur as a unique condition without compromised accommodation (see discussion previously). However, when the CI condition *is* comorbid with AI (CIwAI), it does raise the question of whether AI is the root cause of CI or if it causes pseudo findings of CI, as was suggested by Duane,[28] Jampolsky,[25] and others.[29–31]

For example, several indications of the presence of CI such as a distal NPC and 4 prism diopters more exophoria on the near vs. far cover test could result from hypoaccommodation during testing. Suggestive evidence that this may occur during NPC testing is our finding that AI-only children have distal NPC results similar to CI-only children with mean values of 6.0 cm and 6.13 cm, respectively (see Table 1). This is significantly lower than the group with

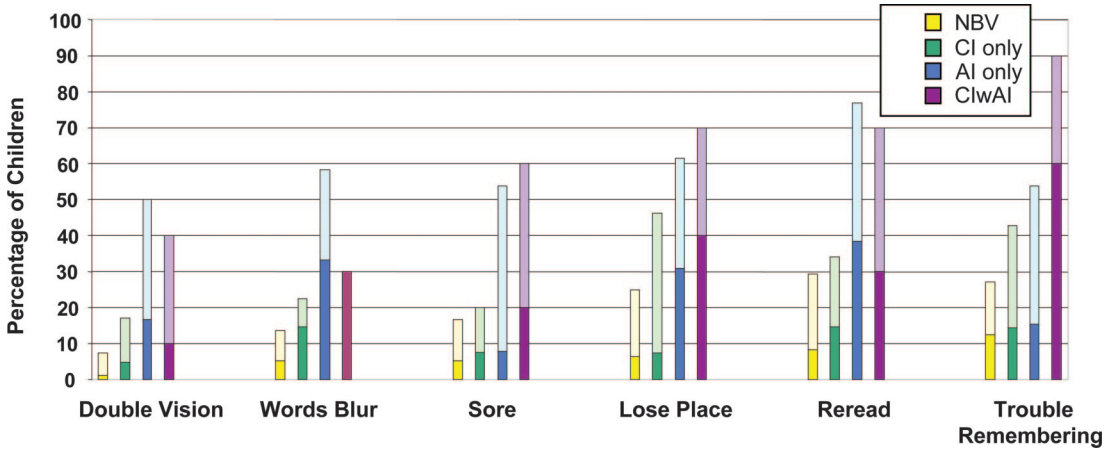

FIGURE 3.

Distribution of the percentage of children in each group responding at a symptom level of "sometimes" (lighter shade) and "fairly often or always" (darker shade) to the six symptom survey questions that best distinguished the three clinical groups from normal binocular vision (NBV). Total column height represents response at a symptom level of "sometimes, fairly often, or always." Different bar hues represent the different groups: NBV = yellow; convergence insufficiency only = green; accommodative insufficiency only = blue; convergence insufficiency comorbid with accommodative insufficiency = purple.

NBV (mean NPC value of 2.2 cm, $p = 0.03$). This suggests that the NPC test is not just a test of voluntary convergence to a near target, but can be contaminated by insufficient accommodation. The higher exophoria for a near target compared with a far target, and hence the low AC/A in CIwAI, may also turn out differently if response AC/As (which measure the accommodative response during testing) rather than stimulus AC/As (which assumes the accommodation is accurate to the target) were recorded.

Importance of Differentiating CI-Only From CIwAI

Future research on the CIwAI condition should incorporate simultaneous measurements of accommodation while a CI workup is conducted. If CIwAI is in fact a pseudo-CI condition, this clarification would affect its treatment. For instance, base-in prisms would not be an appropriate treatment if the source of the presumed CI is hypoaccommodation, whereas accommodative therapy would be. Some clinicians have reported improved performance on PFV and NPC when a pseudoconvergence insufficiency is retested with low-powered plus lenses, which apparently allows the patient to accommodate more accurately.[16] This suggests that plus lenses might also be an appropriate treatment for pseudoconvergence insufficiency.

Future research comparing the efficacy of various treatment paradigms for CI must consider accommodation. For treatment groups to be equivalent, pretreatment measures of accommodation, specifically accommodative amplitude, should be considered. Efficacy of different treatment paradigms, including how well each reduces symptoms, should include posttreatment measures of accommodative amplitude. For instance, are symptoms reduced because accommodation is treated in one therapy paradigm but not in another? Two recent studies comparing the efficacy of pencil pushups, vision therapy/orthoptics, and placebo therapy had very different outcomes.[27,32] The study with prepresbyopic adults was equivocal, whereas the study with children showed statistical and clinical improvement in only the vision therapy group when measured on symptoms, positive fusional convergence, and NPC. A confounding variable in this latter study was the pretreatment demographics of the three groups. The vision therapy group's mean accommodative amplitude met Hofstetter's criteria, whereas the pencil pushup and placebo groups' mean amplitude were 4 D and 5 D below the normative values for the mean age of the group. Because this accommodative deficiency would not have been addressed with pencil pushups or placebo therapy, it may be the reason that symptoms and the NPC remained at pretreatment levels.

In light of our research findings, clinicians who prescribe pencil pushups to patients with CI (who, if symptomatic, are likely to have a comorbid AI condition) may want to modify the exercise and provide a good accommodative stimulus with instructions to keep the target as clear as possible. Orthoptics, exercises prescribed by ophthalmologists for CI, generally do not include accommodation therapy,[33] whereas vision therapy, exercises prescribed by optometrists, typically do.[32] This difference may explain the disparity in opinion between these groups on the effectiveness of vision therapy for CI. Inclusion of accommodative therapy into orthoptics' regimen of exercises would be judicious, especially when a differential diagnosis of CI with comorbid AI (CIwAI) is made.

Are Other Conditions a Cause for Symptoms Seen in AI-Only and CIwAI?

Some of the symptoms found to be significantly higher in the AI-only and CIwAI children, sore eyes, double vision, and words blur, could be considered lower-order ocular plant or oculomotor/accommodative in origin. The symptoms "lose place" or "reread" could be either oculomotor/tracking in origin or point to a deficiency in higher-order visual processing or even gross cognitive processing. "Trouble remembering" could clearly fall into this latter category. It is possible that immature or inefficient lower-level deficiencies distract from and interfere with efficient higher-order processing. It is also possible that higher-order deficiencies such as poor comprehension or inattention could interfere with lower-order functions, like accurate tracking. Although we have documented a strong association of these symptoms with the presence of AI, we cannot assume a causal relationship.

Some recent studies have suggested an overlap in symptomology, and a possible comorbidity, in children diagnosed with learning disorders such as attention deficit disorder/attention deficit hyperactivity disorder (ADD/ADHD) and dyslexia and children diagnosed with AI and CI.[34–38] Although it is possible that some of the symptomology of the CIwAI and AI-only children in our study could be a result of a comorbid ADD/ADHD or dyslexic condition, it seems unlikely. In the two studies that evaluated comorbidity and included evaluation of the visual system, accommodative amplitude was not significantly different from controls in either the dyslexic group[38] or the ADD/ADHD group.[34] Thus, the hallmark anomaly associated with symptoms in our study, accommodation, does not seem to have a high comorbidity with ADD/ADHD or dyslexia. In addition, almost 80% of the symptomatic AI-only group in our study were females, whereas males are more likely to have ADD/ADHD.[39] In summary, it is unlikely that ADD/ADHD or dyslexia is more highly represented in the AI-only or CIwAI subjects compared with CI-only or NBV subjects in our study and thus not a confounding variable.

Finally, reported overlap in symptoms in ADD/ADHD and possible comorbidity with AI and CI is confounded by the way in which ADD/ADHD is diagnosed, typically with a behavioral checklist (Conner's survey[40]) that includes many AI and CI symptoms.[36] To establish comorbidity, newer objective methods to diagnose ADD/ADHD and a nonclinical population study design should be used. A study that controls for these confounding factors may lead to an improved Conner's survey and better differential diagnosis. Until then, ADD/ADHD should be a diagnosis of exclusion that includes differential diagnosis of AI and CI.

Failure to Find Symptoms in CI-Only?

In keeping with the recognized need to standardize CI and AI classification and to facilitate comparative and meaningful research, we adopted the CI classification system used by the CITT Group.[11,14] The strength of this system lies in using several measures of convergence: tonic vergence (cover test), fusional vergence (PFV), and the NPC to diagnose CI. However some may argue that the cutoff values are too low.

The CITT group uses a NPC value of $\geq$6 cm to indicate a sign of CI, whereas others have used 8 cm or 10 cm.[41,43,44] Which one

is correct? When choosing a cutoff value, one must consider the instructional set, the NPC target, the zero point from which the break point is measured, and the method to determine break point (subjective diplopia, examiner observation of loss of fusion, or both). Unfortunately, there are few published norms in which all of these variables are described.[21] Very different normative values can result just by a difference in target. Siderov found a 2.6-cm difference for prepresbyopic subjects when NPC was tested using a RAF acuity target (thin vertical black line with small black fixation dot) vs. a pencil tip.[42] An even larger difference might be expected when comparing NPC measurement with a penlight vs. a Snellen letter. Letourneau used a value of >10 cm as diagnostic of CI, but he used a penlight target and the break point was based on the examiner's observation of loss of fusion.[43,44] A penlight target is a diffuse low spatial frequency target that would minimize a blur response from the accommodation system reducing any accommodation-driven convergence response through the AC/A link. Additionally, the low spatial frequency content of a penlight target would allow a larger fusion limit because Panum's limits increase proportionally with the spatial coarseness of the fusion stimulus.[45]

We used a high-contrast, high spatial frequency target, a 20/30 black letter on a white background. Our instructional set was "try to keep it single and let me know when you see it double," which would encourage a nearer break point than "tell me when it doubles." We used subjective diplopia or examiner observation of loss of fusion, whichever occurred first. All these parameters would bias the break point to be less distal. However, we repeated some analyses of our data to see if using different parameters would affect our results.

We repeated the one-way ANOVA comparing the symptom score across the four groups but redefined our CI definition so that a NPC ≥8 cm was required to indicate a sign of CI. We determined this cutoff by using our definition of NBV (see "Methods") but leaving the NPC value undefined. Only 5% of the children with NBV had a NPC >8 cm. This method excluded children with known binocular or accommodative anomalies, which could skew the NPC values. Using this 8-cm NPC criteria for our CI definition, there was little change in the mean group symptom scores for CI-only (original 12.9 vs. 13.4 new) and CIwAI (original 22.8 vs. 20.4 new). The CIwAI symptom score remained significantly higher than the NBV score, whereas the CI-only symptom score remained insignificant ($p = 0.006$ and $p > 0.05$, respectively, Tukey significant p value = 0.016, adjusted for multiple comparisons).

We repeated the Kruskal-Wallis with the NPC value of 8 cm to determine which of the 15 symptom survey questions best distinguished between the four groups of subjects and found similar results as before, except for the symptom "double vision," which was no longer marginally significant ($p = 0.02$). We also repeated the Mann-Whitney test and the results were consistent with earlier results. Although we felt comfortable with our choice of 8 cm for these additional tests, we also compared the symptom scores of CI-only children with a NPC >10 cm vs. a NPC <10 cm. We found mean scores of 11.63 and 13.71, respectively, which were not significantly different ($p = 0.550$). We repeated this same analysis comparing CI-only children with near phorias >10 Δ exophoria vs. CI-only children with near phorias <10 Δ exophoria and again found no difference in the symptom scores ($x = 14.63$ and $x = 13.03$ respectively, $p = 0.774$).

Improving the CISS-V15 Symptom Survey

Our analysis of the 15 symptom questions that make up the CISS-V15 survey reveals that the survey could be shortened and remain a viable measure of symptoms for children with AI-only and CIwAI. The symptoms which best differentiated these clinical groups from NBV were: sore eyes, trouble remembering, lose place and reread (significant at $p \leq 0.003$) and double vision and words blur ($p \leq 0.006$). "Tired eyes" and "read slowly" were not statistically significant after adjustment for multiple tests ($p < 0.05$) but may have clinical significance. The remaining symptoms, "uncomfortable eyes, headaches, sleepiness, lose concentration, words swim, eyes hurt, and eyes pulling" were not significantly different than NBV ($p > 0.05$) and could be eliminated, shortening the survey to half its current length.

Our analysis of specific symptoms also reveals that the use of the total symptom score masks some symptomology in CI-only children, specifically the symptom "lose place," which was significant on the proportion analysis ($p = 0.008$, adjusted for multiple tests), although not statistically significant on the Kruskal-Wallis analysis ($p = 0.03$).

One final recommendation would be to include a question that accesses time spent doing near work. Although this research has shown that the CISS-V15 survey would not be sensitive to picking up CI-only children, it is also important to realize it would not pick up any child who has a symptomatic visual condition but who appears asymptomatic because he or she avoids near work. Because the sensitivity and specificity of this survey for detecting convergence insufficiency is unknown,[46] this survey is best used as a pretesting clinical tool rather than as a screening instrument. Hence, although the survey itself should be administered to the child directly, the question to access a child's near-work avoidance behavior might best be posed to his or her parent or guardian.

Ocular Motility Tracking

This research study found that all three clinical groups showed significantly higher symptoms than children with NBV on one of the two similar questions of "lose place" or "reread" ($p < 0.008$). In an earlier study,[47] we showed that of the 15 questions on the CISS-V15 survey, these two questions best predicted DEM ratio failure as defined by the 31st percentile level cutoff suggested by Solan and Suchoff.[48] We further showed that the mean DEM ratio of the AI-only, CI-2, and CI-3 groups (no differentiation of CI-only was made at that time) fell below the 31st percentile cutoff. This finding indicates that eye tracking should be evaluated, in children with AI, CI, or both, especially if a child scores high on these two survey questions.

Gender Differences in AI-Only?

A higher prevalence of AI in females than in males has been reported in adults.[12] Our results suggest that this higher prevalence may be established early in childhood. Almost 80% of the AI-only

children in this study were female, although this did not reach statistical significance ($p = 0.07$).

Summary

This investigation has shown that the condition of CI is a separate and unique clinical condition and can occur without a comorbid AI condition (that is, all CI is not pseudo-CI or driven by an underlying AI condition). However, it also shows that CI by itself is not a highly symptomatic condition. Children with CI only score no higher than children with NBV on the 15-question CI symptom survey (CISS-V15). Previous reports of high scores on this survey for the condition of CI are likely the result of preselecting symptomatic CIs[15,26,27,48] and of including subjects with a comorbid AI condition.[11] We found that only when the CI is comorbid with AI, do children with CI score higher than children with NBV, strongly suggesting that the high score is driven by the AI condition. Children with AI-only score significantly higher on this symptom survey than children with NBV, reinforcing this conclusion.

By differentiating CI-only from CIwAI, a better understanding of the clinical profile of CI is accomplished. Simultaneous measurement of accommodation during vergence testing may improve our understanding of the clinical presentation, and possibly the etiology, of CI and thus help in its prevention or treatment.

Research comparing the efficacy of treatment paradigms should make the distinction between CI-only and CIwAI and be careful that accommodative amplitude is equal in pretreatment demographics of the groups to be compared. Posttreatment accommodative amplitude should be evaluated for its influence on other posttreatment values, including near phorias, NPC, and symptoms. Whether the treatment paradigms being compared include accommodative therapy should also be specified.

Further work on ocular motility tracking deficiencies in children with AI-only, CI-only, or CIwAI is needed. Overlaps in symptomology in children with accommodative, binocular, and ocular motility deficiencies with symptomology in children diagnosed with ADD/ADHD and dyslexia emphasizes the importance of differential diagnosis of these conditions.

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APPENDIX
CISS-V15 Symptom Survey Questions

1. Do your eyes feel tired when reading or doing close work?
2. Do your eyes feel uncomfortable when reading or doing close work?
3. Do you have headaches when reading or doing close work?
4. Do you feel sleepy when reading or doing close work?
5. Do you lose concentration when reading or doing close work?
6. Do you have trouble remembering what you have read?
7. Do you have double vision when reading or doing close work?
8. Do you see the words move, jump, swim, or appear to float on the page when reading or doing close work?
9. Do you feel like you read slowly?
10. Do your eyes ever hurt when reading or doing close work?
11. Do your eyes ever feel sore when reading or doing close work?
12. Do you feel a "pulling" feeling around your eyes when reading or doing close work?
13. Do you notice the words blurring or coming in and out of focus when reading or doing close work?
14. Do you lose your place while reading or doing close work?
15. Do you have to reread the same line of words when reading?

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