Convergence insufficiency--a major review

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Convergence insufficiency; Accommodation; Exophoria; Fusional convergence; Vision therapy; Orthoptics; Prism; Asthenopia; Eyestrain

ABSTRACT
Convergence insufficiency is a common binocular vision disorder affecting approximately 5% of the population in the United States. It is often associated with a host of symptoms that occur when doing near work, such as reading and computer viewing. This article reviews the existing literature on convergence insufficiency including etiology, diagnosis, sensorimotor findings, and management.

Definition

Convergence Insufficiency (CI) is a binocular vision disorder, first described by von Graefe[1] in 1855 and later elaborated by Duane[2] and is typically characterized by the following signs: 1) exophoria that is greater at near than distance, 2) a remote near point of convergence (NPC), i.e., a breakdown in convergence greater than 3 inches, or 3) decreased positive fusional convergence (PFC) at near.[2,3] It often is associated with symptoms such as double vision, eyestrain, headaches, blurred vision, and loss of place while reading or performing near work; however, not all patients present with symptoms.

Throughout the years, and even today, numerous investigators and eye care providers have used various definitions in the diagnosis of CI. Some have used only a receded NPC to diagnose CI[4,5] regardless of phoria or PFC, whereas many others believe that an exophoria greater at near must be present, along with either a reduced NPC or PFC. Others feel that both the NPC and PFC should be reduced in the presence of an exophoria before a definitive CI can be diagnosed.[6]

In a clinical study, it was found the 55% of patients had no signs of CI; 33% had 1 sign; 12% had 2 signs; and 6% had all 3 signs.[6] The most common finding in those patients with a CI, who did not demonstrate all 3 signs of CI, was a receded NPC. In some cases, a CI may be diagnosed in the presence of asthenopia associated with convergence, but in the absence of a receded near point of convergence, exophoria at near, or reduced positive relative convergence.[3,7] The definition of CI has important diagnostic and treatment implications. The Convergence Insufficiency Treatment Trial Study Group (CITT Study Group) has been studying a specific condition in which all 3 signs are present along with symptoms. In this report, we define this condition as a symptomatic "classic" CI, and patients who do not demonstrate all 3 signs, a "common" CI. Without consistent diagnostic criteria, studies determining prevalence, characteristics, and treatment results are difficult to compare.

Epidemiology

The prevalence of CI is not truly known because no population-based studies are available. There is great variability in the reported prevalence of CI ranging from 1.75 to 33%.[4,8-14] with the average prevalence reported to be approximately 5%. This variability can be attributed to differences in the definitions of CI, the sample studied (clinic samples vs general population), and differences in testing protocols (some studies measure near point of convergence with a pencil, whereas others use an accommodative target that may alter measurements). Duane,[2] and White and Brown[10] reported a prevalence of 7.5% CI. Kratka and Kratka[9] reported that 25% of patients seen in a general ophthalmologic practice had at least 1 finding of CI, and 50% of those who had 1 sign had all 3 signs with further testing. They reported that 75% of their CIs were symptomatic and were diagnosed between the ages of 20 and 40 years. Neither of these studies provided information as to how their population was selected, i.e., definition of CI, age, or sex.

The best population estimates available are from 3 studies of North American school-age children who were tested in their respective elementary schools.[5,15,16] The estimates ranged from 2.25% to 8.3%. However, the definition of CI was not uniform among the studies. Whether the prevalence of CI varies among ethnic/racial groups is unknown.

Many older studies imply that CI is not common in children, because symptoms are not commonly reported until the second or third decade of life.[4,8,13,14] Recently, Wright and Boger[17] suggested that symptoms of blur and diplopia found in children are a result of interpretation of normal physiologic phenomena. However, they provide no documentation to support this position. In addition, if the symptoms were a consequence of normal physiologic phenomena, one would not expect to find a difference between active vision therapy versus placebo.[18] It had been assumed that young adults spend more time performing near point work than children, thus, young adults are more likely to complain of symptoms.

Recent studies by members of the CITT Study Group have found a higher prevalence of CI in children than had been previously assumed.[16] Fifth and sixth graders were screened to determine both the presence and severity of CI. These children were classified according to the presence and number of the following clinical signs: 1) exophoria at near, 2) insufficient fusional convergence, and 3) receded near point of convergence. Twenty-one percent demonstrated some evidence of a CI: 8% had exophoria at near, 9% had exophoria at near with an additional clinical sign, and 4% had classical CI with all 3 clinical signs.

There are no studies reporting the incidence of CIs in families, although this author has noticed a strong familial tendency for CI.

Symptoms

The most frequently reported symptom for CI is discomfort after reading or computer work,[8,13,19-21] which usually occurs at the end of the day.[13,21] Other symptoms include frontal headaches,[11,13] eye ache, a pulling sensation, heavy eyelids, sleepiness,[11] diplopia,[8,11-13,22-24] loss of concentration,[10,11] blurred vision,[8,13,22,23] tearing,[10] and dull orbital pain. Less common complaints include nausea, motion sickness,[3] dizziness,[4,8,14] panoramic headaches,[8,13,14] gritty sensation in the eyes, and general fatigue. Some CI patients report poor "depth perception," e.g., trouble parking a car or trouble playing tennis.[3] Two other common complaints noted by patients with CI are car sickness and migraines, which, in this author's experience, decrease with therapy. Patients with CI often complain of migraine headaches, which occur immediately after performing excessive near work and after the first few sessions of vision therapy. However, these migraines disappear with treatment. Thus, it might be presumed that in some patients with CI, extensive close work triggers migraine episodes.[25]

Because there are no population studies of children or adults showing objective findings of CI, the true prevalence of asymptomatic CI is unknown. In the only large-scale, randomized clinical trial of CI in children, the 5 most frequently reported symptoms were "loses place while reading" (49.8%), "loses concentration while reading" (45.3%), "needs to reread the same line of words when reading" (44.8%), "reads slowly" (40.3%), and "has trouble remembering what was read" (38.0%).[26]

Hirsch[27] reported that 38% of 48 university students referred for treatment for CI complained of eyes tiring and sleepiness after doing close work for any considerable length of time, 35% experienced headaches, and 18% experienced stinging or burning of the eyes. Kent and Steeve[11] reported that 60% of their patients with CI had headaches, 49% experienced blurring of print, 34% had ocular fatigue, and 21% had intermittent diplopia. As expected, many patients had more than 1 symptom. Burian,[23] in a small study, reported that 18% of patients with CI are asymptomatic. The absence of symptomatology has been presumed to be because of either suppression,[5] avoidance of near visual tasks,[28] high pain threshold, or monocular occlusion. Symptoms associated with CI may negatively affect a person's quality of life by interfering with school, work, and leisure activities performed at near.

These studies were all performed before the rapid increase in computer use. Currently, the leading reason patients make appointments for eye examinations is because of symptoms associated with computer use.[29,30]

Sheedy[29] and Sheedy and Bergstrom[30] surveyed 1,307 optometrists to determine the type of symptoms associated with computer use. The most commonly reported symptoms (in order of frequency) were eyestrain, headaches, blurred vision, dry eyes, irritated eyes, neck pain, photophobia, and diplopia. Sheedy et al[31] indicated that two-thirds of the symptoms associated with computer use were also associated with diagnosable visual anomalies. Computer symptoms associated with dry eye[31] resulted in burning or stinging from decreased blink reflex. (It has been estimated that computer-related visual complaints cost at least $1.2 billion annually in eye care, which does not account for decreased work efficiency or quality-of-life issues.[29]) Because approximately 5% of the population has CI, it would not be surprising that patients with CI make up a significant number of symptomatic computer workers.

One may simulate asthenopia induced by reading or computer use by measuring vergence amplitudes with prisms and accommodation with facility tests.[3,32] Many patients with symptomatic CI will, when queried, report symptoms found during or after testing to be similar to those found while reading or performing other near tasks.

The association of CI and symptoms in children has been investigated by the CITT Group who developed the Convergence Insufficiency Symptom Survey (CISS).[33-35] The CISS is a questionnaire with 15 questions designed to quantify symptoms associated with reading and near work. Each question requires a verbal response of "never, infrequently, sometimes, fairly often, and always." The highest possible score is 60, and the lowest possible score is 0 (see Appendix 1 for the questionnaire).

Symptoms were measured prospectively on school-age (8–13 years) children with CI and children with normal binocular vision (controls).[34] The mean (± standard deviation [SD]) CI Symptom Survey score for the children with CI was 30.8 ± 8.4, whereas for the children with normal binocular vision, the score was 8.4 ± 6.4. Good discrimination (sensitivity, 96%; specificity, 88%) was obtained using a score of >16. Thus, children with CI showed a significantly higher CISS score than children with normal binocular vision. Additionally, Borsting et al.[33] compared patients who responded to each question (symptom) "fairly often" and "always" with CI and those having normal binocular vision. It is readily apparent when looking at Figure 1 that for each symptom there is a significant difference between the CI group and normal subjects. These differences between "normals" and CIs should dispel the notion that symptoms are related to a child's interpretation of normal physiologic phenomena.

The CISS was also used to evaluate symptoms in adults age 19 to 30 years by comparing a group with symptomatic CI with those with normal binocular vision.[35] The mean CI Symptom Survey scores were 37.3 ± 9.3 and 11.0 ± 8.2 for CI and the normal binocular vision groups, respectively. Good discrimination (sensitivity, 97.8%; specificity, 87%) was obtained using a cutoff score of ≥21 for adults. This cutoff score was higher than the cutoff of 16 found for children with symptoms. Figure 2 depicts the incidence of each symptom in children and adults. In general, adults reported a higher frequency of occurrence for each symptom on the CISS. The pattern of response differed between children and adults on 6 of the CISS

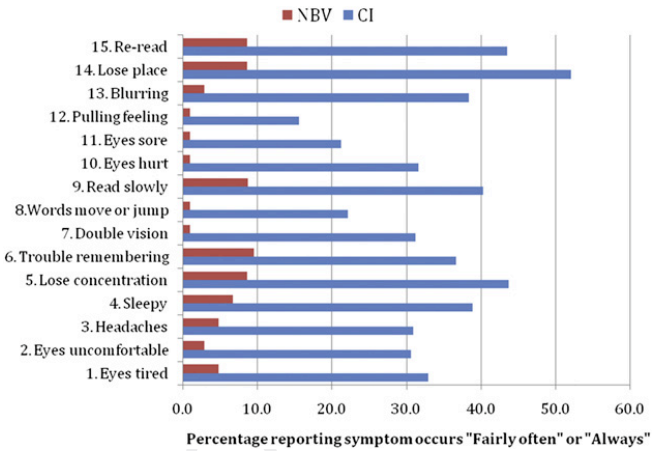

Figure 1 Symptoms of patients with normal binocular vision (NBV) and CI. The CISS was administered to subjects with NBV and subjects with a CI. Mean scores for each question are presented for both the CI and NBV group. Subjects with NBV and CI have clinically different scores on each of the 15 questions. (Revised from Borsting et al.[34])

items. Adults reported a higher frequency of tired eyes, uncomfortable eyes, eyes that hurt, sore eyes, pulling around the eyes (P = 0.003) and blurriness when reading or doing near work. The most frequently reported symptom among children was loss of place while reading or performing near work; 58% reported that loss of place occurred fairly often or always. This was followed by sleepiness (48%) and reading slowly (47%). In contrast, "eyes feeling tired" was the most frequently reported symptom by adults (72%) followed by "eyes feeling uncomfortable" (70%).

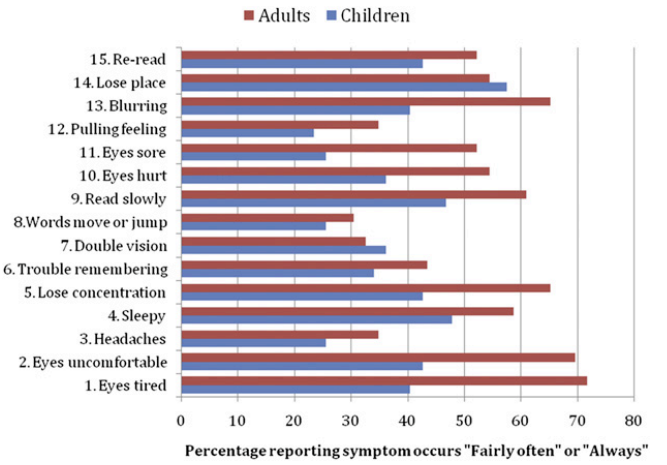

Figure 2 Distribution of symptoms in CI in children and adults. The CISS was administered to both children and adults. Mean scores for each question are presented to both the CI and normal binocular vision group. Generally, adults have more severe symptoms especially with the regard to asthenopia versus symptoms related to reading (Revised from Borsting et al. 34 and Roust et al[35].)

The results of these studies suggest that the CISS is a valid and reliable instrument that can be used clinically or as an outcome measure for research studies for patients with CI. However, all scaled symptom questionnaires have some limitation. They are sensitive when symptoms of asthenopia are diverse, e.g., patient has headaches, double vision, loss of concentration, but not when the patient exhibits only 1 symptom, e.g., diplopia. If a patient only has 1 symptom that occurs all the time, then the symptom score would only be equal to 5, and the patient would be considered statistically normal. Elimination of the symptom by therapy would only result in a decrease of 5 points on the CITT questionnaire. Thus, clinically, one must use the questionnaires with these limitations in mind. Even with this limitation, we suggest that the CISS be used diagnostically to detect and quantify CI before treatment and after treatment to measure change.

Sensorimotor findings

Phoria

Passmore and MacLean[13] noted that 79% of their patients with CI had exophoria at near, 18% had orthophoria, and 3% had esophoria. Cushman and Burri[36] reported that 63% of CI patients exhibited an exophoria on cover testing at near. In the CITT (N = 221) the mean (SD) clinical findings were 2^{Δ} (2.84) exodeviation at distance and 9.3^{Δ} (4.4) exodeviation at near. These findings were not derived from population studies; however, most of the patients with CI had an exophoria. The presence of abnormal exophoria at near is not necessary for the diagnosis of common CI.

Fusional convergence

The majority of patients with CI have insufficient PFC amplitudes at near.[3,14,22] Duane[2] stated that a CI "frequently (had) decreased abduction of 5° to 6° (~8–10Δ), but not more than 9° (~15Δ), prism convergence usually decreased to 8° to 12° (~14 20Δ) or less." Furthermore, Passmore and MacLean[13] considered fusional amplitudes measuring 8 to 10D to be low, Mayou[21] regarded 10 to 20D to be low, Hirsch[27] regarded 12D to be low, and Mould[19] regarded 15D to be low. In the CITT, the mean (SD) positive fusional convergence break/recovery at near was 12.7 (64.69)Δ /8.8 (64.5)Δ. PFC of less than 15D would be considered abnormal for patients with CI and the general population. Low PFC is associated with asthenopic symptoms.[37-39] Variability in measurement of PFC occurs with the stimuli used; for example, size, illumination, speed of measurement, and instructional set all affect PFC.[40] However, when using a large fusional stimulus, presented under the same conditions, measurements are fairly repeatable.[41] Repeatability decreases with smaller targets, such as the single line of letters used with traditional phorometric testing.[42,43] It should be noted that the measurements do not account for the effort expended; thus, it is not uncommon for symptomatic patients in whom symptoms from testing develop to have normal amplitude measurements. Fusional recovery consists of voluntary convergence and convergence in response to spatial disparity. Hirsch[27] reported that the recovery finding is low in patients with CI. Cooper and Duckman[3] suggested that the recovery point is probably a better indication of fusional potential over time. The recovery represents the patient's ability to voluntarily regain fusion on the basis of sensory information.

There is a paucity of data regarding slow vergence or vergence adaptation in symptomatic CI.[44] However, it is currently believed that asymptomatic CI patients have normal slow vergence, whereas patients with symptomatic CI have reduced slow vergence.[45,46]

Near point of convergence

The near point of convergence is the point to which the lines of sight are directed when convergence is at its maximum. According to Duane,[2] a receded NPC (NPC .3 inches or 7.5 cm) is the most consistent clinical sign found in persons with CI. In a clinical sample of 8 to 12-year-old children with exophoria at near who also had 1 clinical sign of CI, a receded NPC was a more common finding than reduced PFC (27% vs 17%). Thus, it is frequently used to make the diagnosis of CI, often as the sole means of diagnosing the condition.[5,6] Various investigators have reported different pass/fail criteria including 13.1 cm,[17] 9.5 cm,[2] and 7.5 cm (3 inches).[47] Maples and Hoenes[48] reported that the NPC break and recovery does not change significantly with multiple measurements during the same testing session. They suggested that the criterion for an NPC break score to differentiate symptomatic from less symptomatic elementary school children should be 5 cm or more.

Although the NPC is an easy clinical test to administer, there has not been consensus on how the test should be performed, with methodology varying from study to study. Variables include the type (e.g., penlight, ruler, accommodative target) and size of the fixation target, the point from which the NPC is measured (e.g., spectacle plane, bridge of nose, corneal plane, center of rotation of eyes), speed of moving the target, and whether the patient's subjective response of diplopia or the examiner's observation of when an eye deviates is used to determine the NPC break and recovery points. Assuredly, these variations in technique have contributed to the wide variations in pass/fail criteria.

Davies[20] recommended that the NPC be performed 12 times to produce ocular fatigue. According to Davies, symptomatic CI patients will show a decrement of the NPC with repetition, whereas asymptomatic patients may not. Capobianco[49] suggested that the NPC in CIs would recede when a red lens is placed in front of an eye when the NPC was repeated numerous times. During NPC testing, it is common to see head retraction, sweating, facial grimaces, and wrinkling of the forehead in patients with CI.[3,50] This may be indicative of the amount of effort used by the patient to initiate convergence. This response, in this author's experience, is almost diagnostic of symptomatic CI. The test should always be performed with the patient actively trying to converge as much as possible.

Scheiman et al.[51] measured the near point of convergence 3 ways: with an accommodative target, a penlight, and a penlight with red and green glasses. The near point of convergence was also measured using a penlight for 10 repetitions. They reported that the clinical cutoff value for the near point of convergence break was 5 cm and 7 cm for the near point of convergence recovery with either an accommodative target or a penlight with red and green glasses. The use of a pen light with red-green glasses or repetition of the NPC appears to be more sensitive in the diagnosis of subtle cases of convergence insufficiency. A difference of more than 4 cm between the first and tenth repetition suggests a problem. The highest correlation between symptoms and the type of target in this study was with the penlight with red-green glasses. Scheiman et al.[51] suggest that the NPC should be evaluated routinely with an accommodative target. If the NPC is normal, but there are other signs or symptoms of convergence insufficiency, or if the NPC is borderline (reduced break, recovery, or a large difference between the 2), the NPC should be repeated with a penlight with red-green glasses. Pang et al.[52] have reported similar findings. The NPC measured with a red lens in front of 1 eye with a transilluminator was the most sensitive and specific testing method to elicit a diagnosis of CI. Use of a transilluminator or accommodative targets to measure the NPC is slightly less sensitive than measurements with a red lens and a transilluminator. Lastly, measurements with either a transilluminator or an accommodative target yielded similar findings for both normal and CI subjects.

Using a standardized protocol, Hayes et al.[53] established normative values for NPC in 297 children in kindergarten, third, and sixth grades who passed a Modified Clinical Technique vision screening. Moving a single column of 20/30 letters at a rate of approximately 1 to 2 cm/s toward the patient's eyes and measuring from the center of the forehead at the brow, the NPC break was determined as the mean of 3 measures in which either the examiner observed 1 eye deviate or the subject reported diplopia, whichever occurred first. At least 85% of the subjects in each grade had an NPC break ≤6 cm. The mean (±SD) NPC break values for kindergarten was 3.3 (±2.6), for third graders was 4.1 (±2.4), and for sixth graders was 4.3 (±3.4). Based on their findings, Hayes et al.[53] recommend a clinical cutoff value of ≤6 cm for school-age children.

Scheiman et al.[51] suggested that a clinical cutoff for adults should be 5 cm for the NPC break and 7 cm for the recovery. Other studies have used values ranging from 5 to 11 cm for the break, and 8 to 11 cm for the recovery.[2,3,10,50] It should be noted that the Scheiman et al.[51] finding of ≤5 cm as the expected break value for normal subjects compares favorably with the expected break value of ≤6 cm for children found by Hayes et al.[53]

Near point analysis

In 1893, Maddox[54] described the 3 components of the vergence system that were thought to be additive: tonic, accommodative, and proximal, which included voluntary and fusional.[54] More recent information has shifted the paradigm from the Maddox model to a negative feedback control system analysis,[44,55-58] in which closed loop feedback from accommodative blur and disparity vergence work to reduce the errors of blur and diplopia. Disparity (i.e., fusional) vergence is made up of 2 components, a fast component, which responds to immediate vergence demands, and a slow adaptive vergence component with a long time decay, which is responsible for maintaining vergence over a long period of time.
The fast vergence system, which eliminates the initial disparity vergence error, is evaluated with clinical measurements of fusional vergence amplitudes using prism. Slow adaptive vergence, which eliminates the long-term demand on disparity vergence, is evaluated with prolonged occlusion or repeated alternate occlusion and is not normally measured by the clinician. However, the amount of slow vergence may be inferred by noting the difference between the unilateral and

alternate cover tests, the diffeence between the initial and final alternate cover test, or the shape of the fixation disparity curve.[59] Patients with "strong" vergence adaptation (slow vergence) have a flatter fixation disparity curve and are presumed to have fewer symptoms than patients with steeper curves, whereas symptomatic patients have been found to have poor vergence adaptation and steeper fixation disparity curves.[59,60]

Many investigators have attempted to relate phoria magnitude (demand) to positive fusional convergence. Duke-Elder[8] felt that only one-third of the total convergence should be used at 33 cm; therefore, 54△ of convergence should be on reserve for maximum expenditure. Sheard[61] and Hofstetter[37] believed the reserves should be larger than twice the demand. In their studies, Sheedy and Saladin[38,63] reported that using Sheard's criterion was the best method to distinguish between symptomatic and asymptomatic exophores.

Despite the differences in analyses, there is agreement that the fusional vergence amplitudes must be larger than the demand (i.e., magnitude of the phoria) to avoid ocular fatigue. None of the methods of analysis account for the variables, such as amount of conscious effort used to fuse the vergence stimulus, amount of time spent on near work, pain threshold, or type of work. Thus, a truck driver with identical vergence findings might not be expected to manifest the same symptoms as a lawyer who works for long periods of time on a computer.

Accommodation

Poor accommodation has been implicated as a possible cause of CI. Prakash et al.[64] reported that accommodation was reduced in 23% with CI. Von Noorden et al.,[65] Bugola,[66] and Raskind[67] have reported that in a few cases in which CIs did not respond to conventional convergence therapy, accommodative amplitudes were the cause, and these patients obtained symptomatic relief with plus lenses for near and BI prism.

Cooper et al.[39] pointed out that recruitment of patients with CI was challenging when an eligibility criterion of normal accommodation was used. The majority of those failing their criterion had normal amplitudes but showed abnormal accommodative facility on the ± 2.00 diopter (D) flipper test. Rouse et al.[16] reported that the frequency of subjects failing accommodative facility testing increased with the number of CI-related signs. For CI children with 3 signs (classic CI), 78.9% were classified as also having an accommodative anomaly. Marran et al.[68] believes that the symptoms found in most CIs are secondary to accommodative anomalies.

Analysis of all the CITT studies found that approximately 58% of children[69] and 39.1% of adults enrolled in the pilot CITT had accommodative insufficiency (AI) using the Hofstetter definition, i.e., accommodative amplitude in diopters is less than 2 D from age-expected norms.[70] Thus, the majority of children with a diagnosis of CI have an accompanying AI , which should be addressed with treatment.

Sensory fusion

Generally speaking, patients with CI have normal stereopsis (40 seconds of arc or better) on both contour and random dot stereograms.[39] Abnormal suppression on first-degree targets is common in CI and may serve as a sensory adaptation to eliminate diplopia and visual confusion by creating functional monocular vision. In our opinion, the more severe the CI and the longer the CI has been manifest, the greater the probability of suppression with a resultant lack of symptoms.

Reading is one of the few "real-life" flat fusion tasks. The loss of retinal disparity cues in reading may result in a poorer stimulus for binocular alignment, and this may account for patients with CI experiencing symptoms while reading or using the computer but not while performing other near tasks.[3]

Refractive error

There is no correlation between refractive error and CI.[14,22,71,72] Passmore and MacLean[13] found that 52% of their CI sample was hyperopic, 34% myopic, and 14% emmetropic. Smith[72] evaluated the refractive error in patients with CI and found that 38% had low myopia, 57% were emmetropic (±1.00 D), and 5% had hyperopia >1.00 D. In another study, Hirsch[27] found 61% of CI patients had ametropia of 0.75 D or less. In the CITT, the mean spherical equivalent refractive error was less than 0.50 D.[73] These findings are similar to those in the normal population, suggesting that there is no relationship between refractive error and CI.

Relationship to learning/attention

Although the exact relationship of CI and learning has not been established, it has been implicated as a causative factor for reading deficiencies. Eames[74-76] compared good readers with poor readers and found that CI was more prevalent in poor readers. Similar findings have been reported by Park and Burr.[77]

Recently, Granet et al.[78] performed a retrospective study on 266 students with CI diagnosed within an academic pediatric ophthalmology practice. Twenty-six patients (9.8%) had ADHD previously diagnosed (parental report only). Of those having a diagnosis of CI and ADHD, 77% were on medication. Granet et al.[78] pointed out that there was a 3-fold greater prevalence of ADHD among patients with CI compared with the general US population (1.8%–3.3%). The authors suggested that patients with ADHD should have an eye examination to identify the possibility of a concomitant CI.

In another study, Borsting et al.[79] evaluated the frequency of ADHD behaviors in school-age children with symptomatic accommodative dysfunction or CI. They reported that using the Conner's Parent Rating Scale-Revised Short Form (CPRS-R:S), cognitive problem/inattention, hyperactivity, and ADHD index were significantly different than normative values for their subjects. The results from their preliminary study suggested that school-age children with symptomatic accommodative dysfunction or CI have a higher frequency of behaviors related to school performance and attention as measured by the CPRS-R:S.

Although CI is more prevalent in children with learning problems, this does not demonstrate cause and effect. Even though they may be neurologically related, eliminating CI may or may not have an effect on reading. This is subject to further study.

Etiology

Duke-Elder[8] listed the following as possible causes of CI: wide interpupillary distance, delayed development or poorly developed accommodation or convergence, presbyopia, disease or debility, toxemia, endocrine disorders, and anxiety neurosis. Raskind[67] noted a small group of CIs secondary to systemic disorders, including head trauma, encephalitis, drug intoxication, malnutrition, debility, hepatitis, and mononucleosis. Although uncommon, CI can also be secondary to anoxia or heavy tobacco use.[80] Patients with a high exophoria who have diseases that interfere with normal binocular vision, such as cataracts, may demonstrate a gross convergence insufficiency after cataract surgery.[81] Recently, there have been reported cases of CI being diagnosed after laser in situ keratomileusis, resulting in symptoms that leave the patient dissatisfied with the surgical result.[82] Thus, binocular status should be evaluated before recommending cataract surgery, laser in situ keratomileusis, or any other refractive procedure.

Adults with presbyopia often have a large exophoria as a result of age-related loss of amplitude of accommodation secondary to the accommodative-convergence linkage (ACA ratio).[8] In addition, exophoria may even increase as a result of the base-out prism induced in the spectacle reading addition. Although one would expect a multitude of symptoms with ensuing presbyopia, the complaints are relatively few.[83] To offset this induced exo deviation, the presbyopic patient must substitute disparity-driven fusional vergence for accommodative vergence. Over a short period, slow adaptive vergence increases, eliminating the load on the fast, disparity vergence system. If this occurs, the vergence demand decreases, and the presbyopic patient remains relatively asymptomatic.[59] Patients who do not have a compensating slow adaptive vergence mechanism may experience symptoms.

More women than men present with CI in a ratio of 3:2,[12,22,84,85] However, this might be a result of women seeking optometric or medical care more often.[86] The CITT studies suggest a more equal incidence of CI among men and women.

The implication that CI is caused by weak eye muscles or other mechanical difficulties has not been demonstrated. A small study by Jampolsky[87] noted that CI was most often the result of poor accommodation. It should be noted that the high correlation of accommodative anomalies associated with CI may be indicative of general anomalies in both accommodation and vergence without implicating etiology.

Some investigators feel that CI is psychogenic.[50,85,88,89] Only 2 investigators have evaluated the relationship between psychological problems and CI.[71,88] Mellick[71] compared the results of treatment of "normal CI" and "neurotic CI." He reported that 77% of his "neurotics" were cured, 8% improved, and 14% had no change. In the normal group, 78% were cured, 15% improved, and 5% showed no improvement as a result of treatment. He concluded that there was no significant difference between groups. However, one might conclude that if CI was caused by neurosis, then one would not expect a treatment cure rate to be the same as that in normals.

It is important to note, however, that Mellick did not state how he assessed or measured these neurotic tendencies. Also, correlations do not imply cause and effect. Although some investigators feel that CI is of psychogenic origin, there is no evidence to support this claim other than "neurotic" patients often manifest symptoms or verbalize symptoms to a greater degree than "nonneurotic" patients.

Most CIs present without a known systemic or psychological etiology. Symptomatic CI results from a breakdown of accommodative convergence cross-links, fusional convergence, or voluntary convergence interactions.[44] There is significant evidence that the primary culprit is not fast vergence, as previously assumed, but slow adaptive vergence, which takes the load off sustained fast vergence.[56,59,90] In any case, there is a breakdown in binocular vision resulting in ocular fatigue.

During near-point tasks, the eyes must maintain a constant and delicate balance between accommodation and convergence while performing close work. Secondly, accommodation and convergence must maintain a stable position during near work. Third, retinal disparity or stereo cues are reduced during reading, possibly making it more difficult for the eyes to maintain fusion. These 3 factors in combination may explain the ocular fatigue that patients with CI experience when convergence is deficient. Lastly, there might be a genetic component because the condition is often found in families.[3]

Although the majority of CIs are idiopathic, a large number of patients with CI have other concomitant ocular and neurologic anomalies. A CI may result from a head trauma, such as incurred in automobile accidents or gun shot wounds,[91-95] and can be associated with longer periods of coma ($P < 0.001$), presence of cognitive disturbances ($P < 0.005$), and patients' failing to find work in the open market ($P < 0.01$).[93,94] These relationships do not necessarily imply cause and effect. The associated findings or symptoms of CI may represent damage to nearby areas in the brain associated with these functions.[93] Cohen et al. believed that vergence anomalies, which are commonly associated with brain injury, are an expression of permanent damage to the mesencephalic and cortical brain structures[93,94] Acquired brain injury consists of 2 major subgroups: traumatic brain injury (TBI) and cerebral vascular accidents (CVA).[96] In a retrospective analysis of the patients referred to an optometric clinic with acquired brain injury, the most common diagnosis was symptomatic CI. Further analysis of the subgroups found that 43% of the patients with TBI and 35% of the patients with CVA had symptomatic CI.[96]

Recently, several investigators[97,98] reported a very high prevalence of CI in wounded soldiers returning from wars in Iraq and Afghanistan. Brahm et al.[97] performed a retrospective study of TBI sustained while serving in the United States military in Iraq and Afghanistan. They evaluated the relationship of penetrating versus nonpenetrating injuries and individuals with moderate to severe polytraumatic TBIs versus mild TBI. For those with moderate/severe TBI, regardless of whether induced by a blast, the incidence of CI was approximately 43%. Patients with milder TBI had a greater incidence of reading difficulties and a larger incidence of CI. When the data for the milder CI were further analyzed by nonblast versus blast-related injuries, the incidence of CI was 64% and 47%, respectively. Also, nonblast patients with TBI showed a high percentage of AI (74%). Unfortunately, the authors did not present data indicating what percentage of the patients with CI also had AI. From their data, one may conclude that CI, AI, and perceived reading difficulties often are associated

with TBI whether mild or severe. In addition, Goodrich et al.[98] reported a CI prevalence of 30% in 50 soldiers with TBI and Stelmack et al.[99] found a CI prevalence of 28% of 103 soldiers with TBI.

The most common ocular motor disturbance associated with Graves disease is CI.[100] CI occurs relatively early, before most patients with thyroid-related eye disease present with any other signs of noncomitancy. Treatment at this stage, in this author's experience, is successful. Rarely, CI has been the presenting sign of myasthenia gravis.[101,102] CI has also been associated with other binocular anomalies such as Duane's syndrome. In addition, CI has been observed with Parkinson's disease,[103,104] and left middle cerebral artery occlusion.[105] It is of interest that convergence insufficiency associated with Parkinson's improves with administration of levodopa.[104]

Treatment

How do optometrists and ophthalmologists treat CI?

In a survey of 300 San Francisco Bay area optometrists, Scheiman et al.[106] reported that the 2 most commonly prescribed treatments for CI were pencil push-up therapy (34%) and vision therapy/orthoptics (22%), followed by base-in prism (20%), referral (18%), and no treatment (6%).

In a recent survey to determine treatment patterns for CI patients, 863 randomly selected U.S. optometrists and ophthalmologists were asked what treatment they would prescribe for a motivated teenage patient with a classic symptomatic CI who was willing to do whatever was necessary to eliminate his symptoms.[106] Fifty-eight percent of the optometrists and 23% of the ophthalmologists responded to the survey. Among optometrists, 36% recommended pencil push-ups, 22% more extensive home-based vision therapy, 16% office-based vision therapy, 15% base-in prism glasses, and 3% no treatment. Among ophthalmologists, 50% recommended pencil push-up therapy, 21% extensive home-based vision therapy, 5% vision therapy, 28% base-in prism glasses, and 8% no treatment. These surveys underscore the lack of consensus among eye care professionals regarding the most appropriate treatment for CI. Figure 3 summarizes the prescribing patterns for both optometrists and ophthalmologists.[106] Similar treatment patterns were reported by ophthalmologists in India, with 79% prescribing pencil push-ups and 18% recommending synoptophore treatment.[107]

Three different "active" convergence treatments are commonly prescribed for patients with symptomatic CI: 1) home-based pencil push-up therapy, 2) home-based therapy using prisms, computer programs such as Home Therapy System (HTS™), stereoscopes, or free-space fusion cards, and 3) office-based vision therapy.[3,106] Pencil push-ups, the most commonly prescribed treatment, are performed at home with no specialized equipment and little or no follow-up. Office-based vision therapy, on the other hand, involves repeated office visits and therefore is more costly and time intensive.

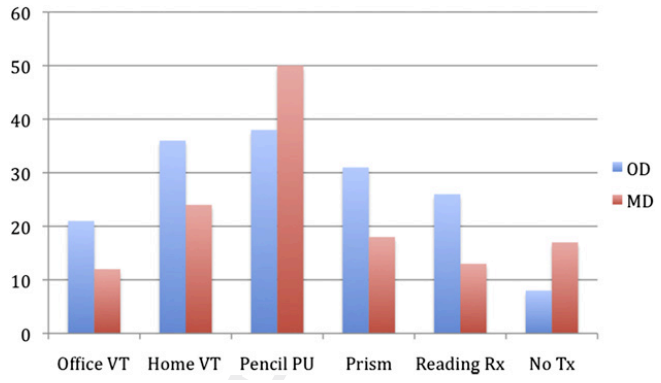

Figure 3 Treatment patterns for CI for optometrists and ophthalmologists. This figure depicts the percentage of either optometrists or ophthalmologists recommending each treatment.[106] Both optometrists and ophthalmologists most often recommend push-up treatment for patients with symptomatic CI as the treatment of choice. A much smaller percentage of optometrist and ophthalmologists advocated the use of home vision therapy/orthoptics.

Treatment options

Home-based pencil push-ups. The basic pencil push-up technique typically prescribed, as described by Duke-Elder years ago, is comprised of "exercises to improve the near point of convergence carried out simply by the subject holding a target at arm's length and then gradually bringing it toward the eye, all the time maintaining bifoveal fixation. These exercises should be carried out several times each day for a few minutes."[108] The use of a background target to provide feedback regarding physiologic diplopia appreciation is often recommended to control for suppression.[18,106,109,110]

Home-based computer vision therapy. The national survey[106] of treatment patterns for CI described above indicated that about 24% of ophthalmologists and almost 36% of optometrists fairly often, often, or always recommend home-based therapy that is more intensive than standard pencil push-ups. In the survey, home-based vision therapy was described as the use of prisms, stereoscopes, or other home-based devices. The use of computer technology in vision therapy became a reality in the 1980s and has become a more important part of vision therapy in the past 10 years.[111,112]

Traditional home vision therapy, besides including pencil push-ups, has included a host of other devices and techniques to improve PFC. In most of the techniques, the demands of the patient are similar, however, with stimuli presented in a different way to improve PFC and voluntary convergence amplitudes. These devices include loose prisms, Brock string, stereoscopes with various targets, anaglyphs, and cheiroscopic cards designed to eliminate suppression and improve PFC. They are prescribed for home use and monitored in the office.

There are several disadvantages of traditional home-based vision therapy including:

1. Traditional techniques often require an experienced doctor/technician to interpret the patient's responses and to use that information to alter stimulus conditions to improve binocular response.
2. Some children may not respond properly using traditional techniques, e.g., the child may "learn" the expected response and has a strong desire to please the therapist; thus, the child may "give the right response" even though not achieving the desired objective.
3. For learning to occur, feedback should be accurate, immediate, consistent, and unbiased. Feedback, using traditional therapy techniques, must be provided by the parent at home. Given human nature, the feedback may not always be as consistent or as immediate as required.

Computerized home-based vision therapy overcomes these 3 potential problems and offers 4 additional advantages.

1. The use of home-based computer software allows for standardization of therapy procedures.
2. Because the computer software tracks the amount of time spent doing the procedure and individual's performance, it provides a measure of adherence.
3. Computerized vision therapy uses principles of operant conditioning by providing immediate feedback regarding correct and incorrect responses.
4. It creates progress graphs for short-term feedback at the end of the session and long-term feedback over time.

Office-based vision therapy. Office-based vision therapy requires a patient to undergo a specific therapy regimen with regular office visits (e.g., once or twice per week). Typically, the therapy is administered by a therapist (OD, MD, orthoptist, or specially trained technician) in the office and supplemented with various home therapy procedures that are prescribed to be performed at home 5 to 7 days per week. The estimated time of treatment for a person with CI is typically 10 to 20 office visits.[109,113]

Base-in prism reading glasses. Prisms are a simple method of decreasing the vergence demand created by the exophoria. Their use has been limited in the management of CI.[106] One of the reasons might be the concern eye care providers have about prism adaptation ("eating up prism: a phenomenon whereby the exophoria increases secondary to wearing compensatory prism).[45] Another potential problem with prism is that the amount of prism prescribed for near may be inappropriate for distance, necessitating the prescription of 2 pairs of glasses. It has been postulated that patients who do not demonstrate adaptation to prism, or have reduced slow adaptive vergence, may be more likely to benefit from prism.[46]

Sheedy and Saladin[38,63] reported that Sheard's criterion did an excellent job of differentiating symptomatic exophores from asymptomatic exophores. However, if Sheard's criterion failed to identify symptomatic exophoria, then Sheedy and Saladin reported that the angular amount of fixation disparity measured should be used (according to Sheedy and Saladin the larger the fixation disparity the greater the chance of having symptoms). From the foregoing, one would assume that prismatic correction, using Sheard's criterion or correcting the angular fixation method, should eliminate asthenopia. However, Saladin[114] points out that there are 3 reasons that prismatic correction satisfying Sheard's criterion, or correcting the angular fixation, might not work: 1) the amount of prism prescribed is relatively small in relationship to the phoria, 2) one would have to prescribe enough prism to flatten the fixation disparity curve to obtain any effect, and 3) slow adaptive vergence would eventually compensate for the prism.

Surgery. Bilateral medial resection has been advocated for orthoptically nonresponsive symptomatic CI.[115]

Effectiveness of treatment options

Until recently, the literature on the effectiveness of various treatments for CI included mostly case studies, case series, retrospective record reviews, and uncontrolled studies.

Since 2005, however, the Convergence Insufficiency Treatment Trial Investigator group completed 4 randomized clinical trials investigating the effectiveness of treatments for symptomatic CI in children and adults (see Appendix 2). These included the CITT child pilot study, the adult pilot study, the base-in prism reading glasses study, and large-scale CITT clinical trial. In this section we review some of the older literature that used lower-quality experimental designs but emphasize the results from prospective, well-designed studies.

Home-based pencil push-ups effectiveness: research evidence. Despite its popularity, there is minimal scientific evidence that pencil push-up treatment is an effective treatment for symptomatic CI. In a prospective, unmasked study investigating pencil push-up treatment, 25 patients between 9 and 51 years of age (mean age 25 years) with symptomatic CI were instructed to perform pencil push-ups at home, for 15 minutes for 5 days a week, to track their performance using a daily log and return for follow-up in 6 weeks.[116] Loss to follow-up was significant (13 of 25). Of the 12 patients who returned for their 6-week follow-up visits, only 7 (58%) of the patients performing pencil push-ups showed a clinically significant improvement in near point of convergence and positive fusional vergence (PFV) as defined by the blur when present and the break when the blur was not present. Nine of the 12 were classified as definite CI and 3 classified as suspect CI. Of the definite CI subjects, 3 showed improvement in NPC and PFV that allowed them to be classified as normal, 3 improved from definite CI to suspect CI, and 3 remained definite CI. Of the 3 suspect CI subjects, 1 improved to normal, and 2 remained CI suspects. Thirty-three percent of those who returned for re-evaluation improved enough to be reclassified as normal, and 11 of 12 reported improvement in symptoms.

In the CITT Child Pilot Study,[117] 47 children age 9 to 18 years with symptomatic classical CI (demonstrated receded NPC, exophoria at near, and reduced PFC) were assigned randomly to receive a 12-week program of home-based pencil push-ups, office-based vision therapy, or office-based placebo therapy. Eighty-eight percent of the subjects completed the 12-week outcome examination. At the 12-week outcome examination for the group assigned to home-based pencil push-ups, the CISS symptom score showed neither a statistical nor

clinically significant change (mean ± SD, 29.3 ± 5.4 to 25.9 ± 7.3; P = 0.24) after the 12-week treatment. Clinically significant "improvement" in the CISS was defined as a reduction of at least 10 points, however, with a final score of greater than 16 on the CISS, whereas a "cure" was defined as a reduction of 10 points and a score of less than 16.[117] For the home-based pencil push-ups group, the NPC improved minimally (mean ± SD, 14.6 ± 7.4 cm to 9.1 ± 5.1 cm; P = 0.08), and the PFV at near showed no statistical improvement (mean ± SD, 12.6 ± 3.2 to 14.5 ± 5.3; P = 0.22). Pencil push-up therapy was found to be no more effective than the placebo therapy.

In the CITT, large-scale, randomized, clinical trial, 221 children age 9 to 17 years with symptomatic CI were assigned randomly to receive a 12-week program of home-based pencil push-ups, home-based computer vision therapy and pencil push-ups, office-based vision therapy with home reinforcement, and office-based placebo therapy.[81] There was no statistically or clinically significant improvement in symptoms for the home-based pencil push-ups group. Although symptoms did improve somewhat, the change was no more than that found in the placebo therapy group in achieving a normal or improved symptom score on the CISS.

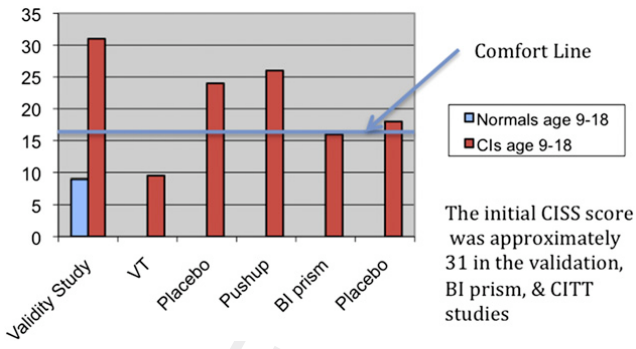

Figure 4 Reduction of symptoms by treatment procedure in children. Treatment modalities for CI were combined and compared in 5 studies.[117, 118, 123, 138] In-office vision therapy provides the highest percentage of patients in 4 studies to achieve asymptomatic scores (16 or less) on the CISS.

Although the post treatment NPC for the pencil push-up group was statistically better than that of the placebo group, the change was not clinically significant. Only 40% of patients achieved a clinically normal NPC in the home-based pencil push-ups group. There was no statistically significant difference in PFV between the home-based pencil push-ups group and the placebo group.

In the CITT study, patients were classified as "successful" or "improved" using a composite outcome classification. This composite outcome classification considered the change in all 3 outcome measures from baseline to the outcome examination. Only 45% of patients in the home-based pencil push-ups group were either "successful" or "improved." This outcome was no better than that of the placebo therapy (see Figure 4).

Finally, in the CITT Adult Pilot Study, 46 young adults 19 to 30 years with symptomatic CI were assigned randomly to receive a 12-week program of the same treatments described above in the Child Pilot Study.[118] Eighty percent of the subjects completed the 12-week outcome examination. Patients in the pencil push-ups group showed a decrease in mean symptom score (37.6 ± 7.7 to 26.5 ± 7.3), although this change was not as large as that observed in the vision therapy group and did not reach the level at which one would conclude that their symptoms were resolved. There was a statistically significant improvement in the mean near point of convergence break measurement in the pencil push-ups group (12.5 cm ± 6.6 to 7.8 cm ± 4.1, P < 0.001), although the changes are not considered clinically significant. Only 46.7% (7 of 15) of subjects in the pencil push-ups group achieved a normal near point of convergence break measurement of <6 cm at the end of treatment (see Figure 5).

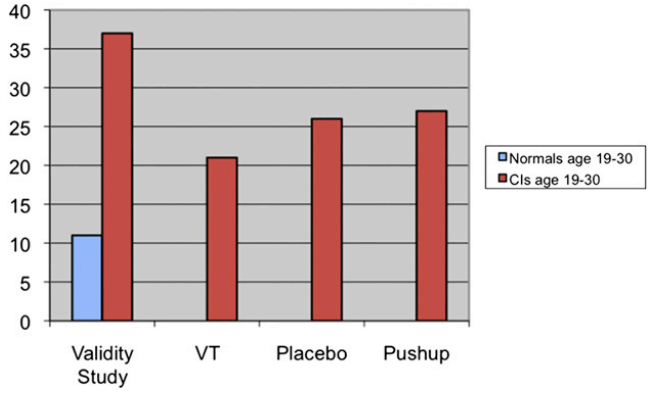

Figure 5 Reduction of symptoms by treatment procedure in adults. Summary findings of treatment as derived from the pilot adult study for treatment of CIs and the validation study.[118]

It is easy to understand the clinical popularity of the pencil push-ups technique because of its simplicity and low cost. Standard, home-based pencil push-ups therapy can be easily taught to patients and prescribed in a very short time. It also requires no or few follow-up visits and no specialized equipment. Therefore, it is significantly less expensive and time consuming for patients. Nevertheless, there is no scientific evidence that pencil push-up therapy is more effective than placebo therapy for the treatment of symptomatic convergence insufficiency.

Home-based computer vision therapy: research evidence. In a well-designed prospective study, Cooper and Feldman[119] used computer-based vision therapy in an operant conditioning paradigm with 8 subjects to determine if vergence therapy improved vergence amplitudes. They used an A–B reversal design. The experimental group (A) received vergence therapy, and the control group (B) did not. (Eventually, the control group became the experimental group, and the experimental group became the control group). During vergence therapy, a correct response resulted in the computer automatically and immediately giving the subject a positive auditory reinforcement (beep) and an automatic increase in the vergence demand. Incorrect responses resulted in an audible "boop" from the computer and a concurrent decrease in the vergence demand. Thus, the behavior of the subject controlled the vergence demand. Success was met with a harder demand, failure, with an easier task. The control group received identical stimuli and reinforcement; however, neither correct nor

incorrect responses resulted in a change in the vergence demand. The results of this study showed that automated computerized therapy resulted in a rapid increase of fusional vergence. Concurrent transference of this ability to other vergence tasks (e.g., vectogram vergence ranges) was also found.

Daum et al.[120] trained 6 subjects who received positive vergence therapy using a slow vergence therapy rate (0.75Δ/s) and 6 subjects who received positive vergence therapy using a fast vergence therapy rate (5.00Δ/s). Six subjects served as controls and did not receive therapy. The therapy was performed using a computerized video display. The duration of therapy was 80 minutes over a period of 4 weeks. All therapy activities were monitored. All vergence evaluations were double masked. Although both groups achieved substantial increases in positive and negative vergence, there were greater changes in the group with larger steps (5.00Δ/s) versus smaller phasic steps (0.75Δ/s). The authors concluded that vergence therapy using a computerized video display was an effective technique for increasing PFC.

Kertesz[121] used computer-manipulated anaglyphs to produce large vergence stimuli. He treated 29 patients with CI who had not responded to traditional orthoptic techniques. Treatment included slowly separating large dichoptic targets in both convergence and divergence directions. Eighty percent of his sample improved PFC and decreased symptoms.

Thus, a number of small studies have indicated that computer-based vision therapy was effective in decreasing symptoms and improving PFC in patients with convergence anomalies.[39,112,120,122] Many of the aforementioned studies used software similar to HTS, although administered in an office/research setting, and have provided a scientific basis for its use in a clinical trial.

Until recently, however, there has been limited research of the effectiveness of computer-based therapy administrated entirely at home. This type of therapy was studied for the first time in a randomized, clinical trial in the large-scale CITT study.[123] The results showed that there was no statistically or clinically significant improvement in symptoms for the home-based

Table 1 Literature review success of vision therapy for CI

Study	Year	No. of subjects	% Cured	% Improved	% Failed	Weakness
Mann[50]	1940	142	68	30	3	b, d, e
Lyle and Jackson[128]	1940	300	83	10	7	
Cushman and Burri[128]	1941	66	66	30	4	b, c, e
Hirsch[27]	1943	48	77	12	10	b, c, e
Duthie[84]	1944	123	88	6	6	b, c, d, e
Mayou[127]	1945	580	65	12	7	b, c, d, e
Mayou[21]	1946	87	92	6	2	b, c, d, e
Mellick[71]	1950	88	77	10	12	b, c, d, e
Passmore[13]	1957	100	82	18	0	c, d, e
Norn[4]	1966	65	9	60	30	b, c, d, e
Hoffman et al.[158]	1973	17	88	–	12	a, d, e
Wick[131]	1977	161	92	–	8	e
Pantano[147]	1982	207	53	43	4	e
Daum[159]	1984	110	41	56	3	d, e
Cohen and Soden[132]	1984	28	96	4	0	a, d, e
Birnbaum et al.[160]	1999	60	62	–	38	e
Total		2182	73.40%	19%	7.60%	

Weakness–a = inadequate numbers of subjects; b = lack of a definition of CI; c = lack of operational definitions for success; d = retrospective design; e = unmasked examiners and subjects.

Cooper et al.[39] designed an experiment to determine if computer-based vision therapy was successful in treating convergence insufficiency and reducing symptoms. They again used an A–B–A crossover design with 7 subjects to control for experimental bias, placebo effects, and order effects. After the experimental phase, all patients exhibited statistically significant increases in maximum PFC compared with that recorded at baseline or the control phase. The mean increase in PFC for all 7 patients was 17.7Δ (SD = 6.9Δ). In contrast, the PFC increase after the control phase was 2.4Δ (SD = 4.1Δ). Statistical analysis found that maximum PFC scores in baseline, control, and experimental phases were significantly different ($F = 7.75$; $DF = 2, 12$; $P < 0.01$). Also, there was a reduction in symptoms as measured on a scaled questionnaire given before and after therapy.

computer vision therapy group. Although symptoms did improve somewhat, the change was no more than that found in the placebo therapy group. Although the improvement in NPC was significantly better than that of the placebo group, the change was not clinically significant. The NPC after treatment in the home-based computer group was no better than that in the home-based pencil push-ups group. Only 39% of patients achieved a clinically normal or improved NPC in the home-based computer vision therapy group. The improvement in the PFV was significantly better (higher) than in the home-based pencil push-ups and office-based placebo therapy groups but significantly less than the improvement in the office-based vision therapy group. Only 33% of patients in the home-based computer vision therapy group were either "successful" or "improved." This outcome was no better than that of the placebo therapy.

Recently, a retrospective study of 43 prepresbyopic patients who completed the HTS was performed to determine the effectiveness of home computerized vision therapy to reduce symptoms in patients with accommodative/vergence anomalies.[124] The initial diagnosis of the patients was unknown, thus, the number of patients exhibiting CI is unknown. Before and immediately after treatment, all patients in this study filled out the CISS. The initial symptoms score was 32.8 (SD = 8.1), and after therapy the mean symptom score decreased to 20.6 (SD = 11.5). These changes were both clinically and statistically significant. Forty percent were cured (score of 16 or less and a change of more than 10 points on the CISS) and 55% improved (a score of less than 16 or change of more than 10 points on the CISS). In addition, average convergence amplitude improved from 22$^{\Delta}$ to 53$^{\Delta}$ after treatment. Average divergence amplitudes improved from 15$^{\Delta}$ to 25$^{\Delta}$. More than 75% of the patients finished the program by 40 sessions (equivalent to 8 weeks). These findings suggest that use of the HTS system results in improved convergence and divergence amplitudes with a concomitant reduction in symptoms. There are clearly differences between this study and the CITT. The subjects' prior diagnostic data and whether a CI was present were unknown. Most of the patients did not reach the CISS criterion score of 16 defined by the CITT study as asymptomatic. Another difference in this study from the CITT study was the requirement of completion of the program. The authors suggested that the HTS system should be used on those patients with symptoms associated with an accommodative/vergence anomaly when in-office vision therapy is not practical.

In a retrospective study, 42 patients with symptomatic CI were treated for approximately 13 weeks using a home-based orthoptic program.[125] Of the 42 patients, 35 were treated with push-up exercises and a home-based computer orthoptic program, whereas the remaining 7 used only the computer orthoptic program. Before treatment the mean NPC was 24.2 cm. The posttreatment mean NPC improved to 5.6 cm. Thirty-nine patients (92.8%) achieved an NPC of less than 6 cm ($P < 0.001$); in addition, positive fusional vergence improved in 39 patients (92.8%). Fourteen patients had a reduction in their near exophoria to less than 5$^{\Delta}$ and 27 patients (64.2%) reported complete resolution of symptoms after treatment. The authors reported that home-based computer orthoptic exercises reduced symptoms and improved NPC and fusional amplitudes in symptomatic CI. They concluded that the computer orthoptic program is an option for treating symptomatic CI. The study had numerous design flaws. The authors did not use a scaled questionnaire or a control group, and the examiners were not masked.

Office-based vision therapy: research evidence. Table 1 lists studies from 1940 to 2002 that have reported on the effectiveness of vision therapy for the treatment of CI.[3,126] The total number of subjects in these studies is 2,182 with a reported "cure" rate of 73.4% (range, 62%–96%). The combined "improved and cure" rate is 92.4%, although various definitions of cure were used. Most of these studies, however, have significant design flaws. Thus, the results, although suggestive of effectiveness of office-based vision therapy, are not conclusive. In today's era of evidence-based health care, these studies would not be considered adequate with regard to study methodology.

Of historical note, many of the studies cited in Table 1 were performed in the 1940s in England to eliminate asthenopia and improve productivity during World War II.[21,36,84,127] Most treatment programs during the war were relatively short (5–11 visits), and therapists concentrated on building PFC, voluntary convergences, and accommodative convergences. Some therapists used antisuppression techniques, whereas others stressed jump vergence (disparity vergence).[21,36,128,84] These studies included nondocumented changes in signs and symptoms associated with CI. For example, Stutterheim[129] and Mann[50] have suggested that visual acuity improved as a function of the elimination of small central suppressions. Passmore and MacLean[13] noted that general tension disappeared and that their patients showed a positive change in personality. Others have reported that migraine headaches often cease at the end of treatment of CI.[13]

In the past, there has been a clinical bias against treating older patients with CI with vision therapy on the assumption that these patients were too old for therapy to be successful.[130] However, Wick et al.[131] treated 191 presbyopic (aged 45–89 years) patients with symptomatic CI with home-based treatment, augmented by in-office treatment, for approximately 10 weeks. He reported a 93% cure rate with 48% needing additional treatment after 3 months of follow-up. Cohen and Soden[132] reported a 96% cure rate in 28 male patients over the age of 60 treated for approximately 12 weeks. Eighty-three percent of their patients maintained their success 9 to 12 months after completing therapy. In a retrospective study, Ciuffreda et al.[133] reported a success rate of more than 90% in eliminating signs and symptoms in patients with acquired oculomotor dysfunction diagnosed secondary to acquired brain injury. The majority of patients showed a form of convergence insufficiency.

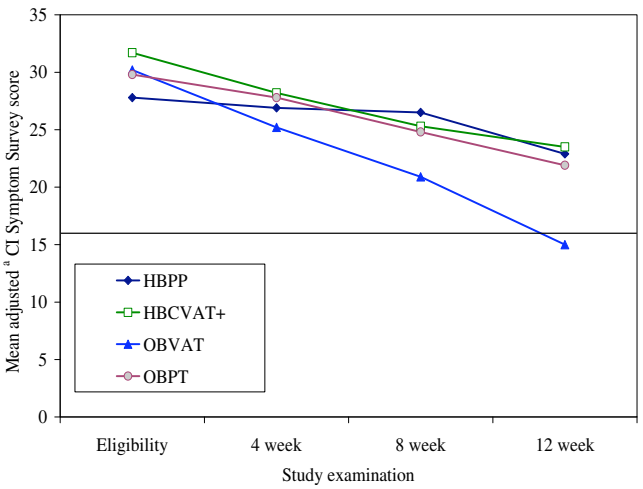

Figure 6 Reduction of symptoms by treatment procedure in CITT. The mean CISS scores are depicted for the masked examinations at baseline which were adjusted from the baselne at weeks 4, 8, and 12 for each arm of therapy: in-office therapy with home supplemental therapy (OB-VAT), office-based placebo therapy with home therapy (sham)(OBPT), home-based pushups (HBPP), and home computerized vision therapy with pushups (HBCVAT+). (From Convergence Insufficiency Treatment Trial Study Group,[123] with permission.)

The 3 CITT studies referred to previously were the first studies that used the gold-standard, randomized clinical trials design to investigate the efficacy of office-based vision therapy in symptomatic CIs.[117,118,123] The 2 pilot studies[117,118] and the large-scale CITT study[123,134] showed that office-based vision therapy with home reinforcement is more effective than either home-based pencil push-ups, home-based computer vision therapy, or office-based placebo therapy for improving both the symptoms and signs of CI.

In the large-scale CITT, after 12 weeks of treatment, the office-based vergence/accommodative therapy group's CISS score (15.1) was significantly lower than the home-based pencil push-ups therapy, home-based computer vergence/accommodative therapy and pencil push-ups, and office-based placebo therapy groups' scores of 21.3, 24.7, and 21.9, respectively ($P < 0.001$ for each comparison).[123,134] Although symptoms improved somewhat with the 2 home-based therapies, these treatments were no more effective in improving symptoms than office-based placebo therapy ($P > 0.38$ for both comparisons). After treatment, 73% of patients assigned to office-based vergence/accommodative therapy achieved a normal or improved (10-point or more decrease) symptom score on the CISS, in contrast to 47% assigned to home-based pencil push-ups, 39% assigned to home-based computer vergence/accommodative therapy and pencil push-ups, and 43% assigned to office-based placebo therapy ($P = 0.006$, 0.0004, and 0.0014, respectively).

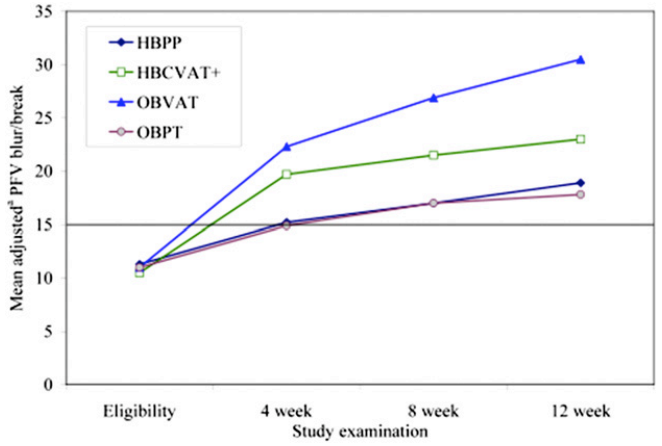

Figure 7 Change in positive fusional vergence amplitudes during the CITT. The positive fusional vergence amplitudes (blur if not present then the break point), from baseline, are depicted for the masked examinations at baseline, which were adjusted at 4 weeks, 8 weeks, and 12 weeks of treatment for each arm, in-office therapy (OBVAT), office-based placebo therapy with home therapy (sham)(OBPT), home-based push-ups (HBPP), and home computerized vision therapy with pushups (HBCVAT+). (From Convergence Insufficiency Treatment Trial Study Group,[123] with permission.)

The office-based vergence/accommodative therapy group showed a significantly improved NPC and PFV compared with the other groups ($P \leq 0.005$). Although the mean NPC of both home-based groups measured significantly closer than the office-based placebo therapy group (pairwise P values all ≤ 0.013), there were no significant differences ($P = 0.33$) between the 2 home-based therapy groups. The mean posttreatment PFV for patients in the office-based vergence/accommodative therapy group was significantly greater than all other groups (pairwise P values all ≤ 0.001) with that of the home-based computer vergence/accommodative therapy and pencil push-ups group being significantly better (higher) than in the home-based pencil push-ups ($P = 0.037$) and office-based placebo therapy groups ($P = 0.008$). The proportion of patients who achieved a clinically normal level for both measures was 73% in the office-based vergence/accommodative therapy group versus no more than 40% in each of the other 3 treatment groups ($P < 0.001$ for each comparison).

Finally, patients were classified as "successful" or "improved" using a composite outcome classification. This composite outcome classification considered the change in all 3 outcome measurements from baseline to the outcome examination. A "successful" outcome was a score of less than 16 on the CISS, a normal NPC (i.e., <6 cm), and normal PFV (i.e., 15^{Δ} and passing Sheard's criterion). "Improved" was defined as a score of less than 16 or a 10-point decrease in the CISS score, and at least 1 of the following: normal NPC, improvement in NPC of more than 4 cm, or normal PFV or an increase in PFV of more than 10^{Δ}. Patients who did not meet the criteria for "successful" or "improved" were considered "nonresponders." Although 73% of patients in the office-based vergence/accommodative therapy group were either "successful" or "improved," 45% of patients in the home-based pencil push-ups group, 33% of the patients in the home-based computer vergence/accommodative therapy group, and 35% of the office-based placebo group (35%) were similarly classified ($P < 0.002$ for each comparison). There were no significant differences between the 2 home-based therapy groups and the placebo therapy group ($P \geq 0.39$ for both).

These results showed that 12 weeks of office-based vergence/accommodative therapy resulted in a greater percentage of patients reaching a predetermined success criteria when compared with home-based pencil push-ups, home-based computer vergence/accommodative therapy and pencil push-ups, and office-based placebo therapy. These findings also show that in-office vergence/accommodative therapy results in a clinically meaningful and statistically significantly greater improvement in symptoms and clinical measures of NPC and PFV for patients with CI.

Figures 6 and 7 depict the dynamic changes of symptoms and PFC over time for each treatment method.[26] There is a significant difference noted from baseline by the fourth week. It is readily apparent that there is a general decrease in symptoms over time in all 4 groups, but with a more rapid decrease in symptoms in the office-based group with supplemental home therapy compared with the other treatments. The mean positive fusional amplitude for patients in the office-based and home-based computer groups began to diverge from the other groups by week 4. In all cases, positive fusional amplitudes improved before improvement in symptoms. As the duration of therapy increased, so did the percentage of patients being classified as "successful" or "improved": 4 weeks (34%), 8 weeks (45%), and 12 weeks (73%).[26] The slopes of the symptoms and fusional amplitude graphs suggest that if therapy is not successful at the 12-week mark, therapy should continue for at least another 4 weeks.

Base-in reading glasses. There are only a few studies evaluating the efficacy of prescribing prisms to decrease the symptoms associated with any binocular anomaly including convergence insufficiency. Worrell et al.[135] prescribed 2 pairs of glasses to a group of patients who had failed Sheard's criterion[61] (i.e., positive fusional vergence finding less than twice the magnitude of the ocular deviation); 1 group was prescribed prism to satisfy Sheard's criterion, and a second group was prescribed a pair of glasses without prism. They found that the application of prism to meet Sheard's criterion was not predictably successful for patients demonstrating exophoria at near (11 of 24 preferred the prism). They noted that better results were achieved in the presbyopic population. Their sample was too small to draw statistical conclusions.

In an unpublished study by Roy and Saladin,[114,136] subjects performed a reading task before and after wearing prisms. They stated that the prisms did not improve the symptoms. Saladin concluded that only vision therapy will be corrective for asthenopic symptoms.

Stavis el al.[137] prescribed prism for 72 children ages 8 to18 years with symptomatic exophoria. They reported a decrease in symptoms and a significant improvement in reading scores (speed, accuracy, and comprehension) on a standardized Gray Oral Reading Test. There were numerous problems with the study design. The questionnaire was not scaled, the questions appear to be biased, examiners were not masked, and there was no control group. Thus, the interpretation of the results from this study is open to question. It should be noted that none of the aforementioned patients had classical CI; the diagnosis was based on measurements of the deviation or Sheard's criterion.

In a prospective double-masked, multicenter, randomized clinical trial, 72 children 9 to less than 18 years of age with symptomatic CI were assigned randomly to base-in prism glasses (distance optical prescription plus prism amount based on Sheard's criterion) or placebo (distance optical prescription and no prism) reading glasses.[138] Patients were instructed to wear the glasses for all near tasks of more than 5 minutes duration. Symptoms were measured using the CISS that was given at the baseline examination and after 6 weeks of glasses wear. The mean CISS score decreased equally (i.e., less symptomatic) in both groups. Patients wearing base-in prism glasses at the initial examination had an initial asthenopia score of 31.6 (±10.4), which became 16.5 (69.2) after 6 weeks of wearing prismatic glasses. Those wearing the placebo glasses had a mean score of 28.4 (±8.8) before wearing glasses and 17.5 (±12.3) after wearing nonprismatic glasses. In children 9 to less than 18 years of age with symptomatic CI, base-in prism reading glasses were found to be no more effective in alleviating symptoms or improving clinical findings than the placebo effect of prescribing any eyeglasses for this age group.

Dusek et al.[139] recently reported on 134 patients with CI (ages 7–14 years) and with reading difficulties who were either prescribed 8$^{\Delta}$ base-in reading spectacles (N = 51) or computerized home vision therapy (N = 51). Thirty-two participants refused all treatment and were designated the control group. Reading speed and accuracy were measured before and after treatment using The Salzburg Reading Test for all 3 treatment arms. In this section, we report only on those that were prescribed prism. Mean reading error scores for the control group were initially 5.34 ± 3.5 and posttherapy 4.66 ± 2.9 with a difference of 0.69 ±1.20, which was not significant, while the prism group initially had a score of 4.92 ± 4.06 and a posttherapy score of 2.12 ± 1.9 with a difference of 2.80 ± 2.82, which was significant. Mean total reading time in seconds for the control group was initially 130.88 ± 61.46, and posttherapy mean score was 127.03 ± 60.59 with a difference of 3.84 ± 4.04, which was not significant; while the prism group initially had a mean score of 108.49 ± 48.68, and a posttherapy score of 87.00 ± 39.60 with a difference of 21.49 ± 13.53, which was significant. Durek et al.[139] concluded that the wearing of prisms at near improved both speed and accuracy of reading. However, it should be noted that the measurements were taken only a month after wearing the prism. Because prism results may be diminished over time because of adaptation, the authors need to present long-term evidence. In addition, the examiner was not masked.

A prospective study of symptomatic CI subjects ages 45 to 68 years was performed.[140] Each subject was assigned 2 pairs of progressive addition glasses, 1 with BI prism and 1 without prism. Subjects wore each pair of glasses for 3 weeks and then completed the CISS. The mean CISS score before wearing the glasses was 30 and decreased to 13 with the BI-prism glasses and 24 with glasses without prism. Progressive addition glasses with BI prism were found to be effective in reducing symptoms of presbyopes with symptomatic CI, at least for the short term.

Surgery. The surgical success rates for CI are variable. The few studies evaluating surgical intervention used small sample sizes, which were retrospective in design and performed only on adults.[141-144] Only 1 study provided any long-term data that demonstrated a high percentage of regression.[145] There is a paucity of information on surgery for children with CI, none meeting the rigor to exclude experimental biases, placebo effects, and more.[146]

Long-term results

There are 3 studies that have evaluated the long-term efficacy of vision therapy/orthoptics for CI. Pantano[147] reported on 207 treated, symptomatic patients with CI (age 10–46 years) who were treated with home-based orthoptic exercises using a stereoscope. The most consistent objective findings before treatment were a remote NPC and reduced distance convergence amplitudes. After treatment, the patients were divided into 2 groups: those that were cured and developed voluntary convergence and those in whom voluntary convergence did not development. The patients were reexamined by Pantano at 6 months and 2 years post therapy. Of the 104 who were cured, 100% were reported to remain symptom free after 2 years. The 103 patients who did not have voluntary convergence regressed, 21% reported symptoms at 6 months, and 88% reported symptoms by 2 years after treatment. This study did not have a control group, and the examiners at outcome were unmasked.

Patients who were asymptomatic after a 12-week therapy program in the large-scale CITT were followed up with for 1 year.[123] Maintenance therapy was prescribed for the first 6 months; followed by no treatment for the next 6 months. Symptoms and clinical signs were measured at the completion of therapy, 6 months and 1 year after completion. The mean change on the CISS, NPC, PFV, and the proportion of patients who remained asymptomatic on the CISS or who were classified as successful or improved based on a composite

measure of CISS, NPC, and PFV were measured. Improvements in symptoms and clinical signs occurring after 12 weeks of therapy were maintained in most children ages 9 to 17 years for at least 1 year after discontinuing treatment, i.e., there were no significant differences in the CISS, NPC, or PFV (P values ≥ 0.077).

Shin et al.[148] evaluated 57 children ages 9 to 13 years who initially had symptomatic CI (N = 27) or symptomatic CI with an AI (N = 30). They were divided into 2 groups: a treatment and a control group. The treatment group received 12 weeks of in-office VT, whereas the control group did not receive any therapy. A quality-of-life survey was used to measure symptoms in both groups. Twenty children in the treatment group were re-examined 1 year after treatment. Symptom scores were significantly different after 12 weeks of treatment in the treatment group ($P < 0.001$), whereas no changes were noted in the control group. A 1-year follow-up examination found that most children maintained the improvement in symptoms and clinical measures after therapy.

Objective outcome measures

In a unique design, Grisham et al.[149] used an infrared eye movement system to objectively measure vergence in a small sample of post orthoptic CI patients. In all other studies, investigators used subjective clinical measures, such as NPC and PFV. Grisham et al.[149] measured eye movements before and after the administration of a variety of accommodative-vergence therapeutic techniques. Before therapy, the subjects could only accurately track vergence stimuli that changed at a slow pace, whereas after therapy, fusional movements were full and accurate to a variety of fusional stimuli. Subjects reevaluated 6 to 9 months after cessation of therapy did not show any evidence of regression. In addition, these patients reported elimination of their symptoms.

Recently, neurologic correlates of both subjects with CI and normal findings were quantified using functional magnetic resonance imaging scans while performing random and predictable convergence and divergence fusional movements[150] a method by which eye movements are recorded objectively. All CI subjects had 18 hours of vision therapy. Subjects in the study were evaluated at baseline, during therapy, 4 months after vision therapy, and a year after vision therapy. Convergence and divergence average peak velocities to step stimuli before therapy were significantly slower in CI subjects compared with controls. Peak velocities are the maximum velocity of the eyes that occur during a vergence response. The slower the peak velocity, the longer it takes the eyes to make a fusional response; it took patients with CI initially up to 2 seconds to fuse a target and 500 milliseconds for normals. After therapy, convergence average peak velocities became normal. The amount of functional activity within the frontal areas, cerebellum, and brain stem increased significantly after therapy on functional magnetic resonance imaging. The NPC was directly correlated to activity in the brain stem. This is the first study to demonstrate neurologic changes after vision therapy.

Underlying physiological changes in successful vision therapy

North and Henson[45] suggested that vergence adaptation can be used to discriminate between symptomatic and asymptomatic CI. They believe that symptomatic CI has poor vergence adaptation, whereas asymptomatic CIs have normal vergence adaptation. Normal vergence adaptation suggests a robust slow adaptive vergence system that eliminates a time-related demand on the fast disparity vergence system. (For a complete discussion of accommodative-vergence modeling see Ciuffreda.[151]) Eight patients with symptomatic CI and "poor" slow adaptive vergence received 8 weeks of vision therapy. After therapy, vergence adaptation and fusional amplitudes were measured. Both findings were found to have improved significantly with a concurrent reduction in asthenopia. North and Henson[45,90] postulated that improved vergence adaptation is the reason for elimination of asthenopia and the reason these patients achieve lasting results. Cooper et al.[39] showed that vision therapy resulted in flattening of the fixation disparity curves with implied improvement in slow adaptive vergence.

Thus, treatment of convergence insufficiency with vision therapy involves the normalization of convergence facility and amplitude, accommodative–vergence interactions, accommodative facility and amplitude, voluntary vergence, and development of improved vergence adaptation.[3,152] Slow adaptive vergence is necessary to maintain vergence over time and reduce the load on disparity–vergence (fast vergence) over time.[59] In the authors' experience, treatment usually results in an initial improvement in fusional amplitudes before symptoms are eliminated. It is not until both accommodative and vergence findings are automated that symptoms are permanently eliminated.

Vision therapy and its relationship to reading

There have been a few articles evaluating the effectiveness of convergence training for children who have reading difficulties. Atzmon et al.[153] divided 62 second graders who had reading difficulties and presumed convergence defects, based on an arbitrary definition of reduced convergence amplitudes, into 2 groups: 1 group received reading tutoring only, and the second group received orthoptics only. Each child received approximately 37 sessions of therapy over 2 to 3 months. At the end of treatment, standardized reading tests were given for both groups. Improvement in reading was marked and equal in both groups, with the orthoptic group enjoying the additional benefit of alleviation of all asthenopic symptoms. Atzmon et al.[153] concluded that orthoptic treatment is as effective as conventional reading tutoring and less expensive.

Recently, Goss et al.[154] studied a sample of fourth graders who were randomly divided into 1 of 2 groups. One group received placebo therapy and the other group active therapy, i.e., "real HTS," a home therapy system designed to use operant conditioning to improve ocular motility, accommodation, and vergence. Few subjects finished either arm of therapy; however, for those who did complete therapy, the trend was that those patients who were in the "real HTS" group had a much larger improvement in reading scores. Goss et al.[154] repeated the experiment without a control group in a group of third graders. The group that used HTS improved their reading scores by 1.8 years compared with placebo and control groups that improved by 0.9 years. Those that did not complete therapy did not perform any better than the placebo or the control groups.

It is important to note that success was directly related to compliance in therapy.

Dusek et al.[139] as previously stated, reported on 134 patients with CI (ages 7–14 years) and reading difficulties, who were either prescribed 8$^{\Delta}$ base-in reading spectacles (N = 51) or computerized home vision therapy (N = 51). Thirty-two participants refused all treatment and were designated the control group. Reading speed and accuracy were measured before and after treatment for all 3 groups. In this section, we are reporting only on the HTS group (the prism group was previously presented in the prism therapy section). Mean reading error scores for the control group were initially 5.34 ± 3.5 and after therapy 4.66 ± 2.9 with a difference of 0.69 ± 1.20, which was not significant; the HTS group initially had a score of .53 ± 3.06 and a posttherapy score of 2.86 ± 1.9 with a difference of 1.67 ± 1.90, which was significant. Mean total reading time in seconds for the control group was initially 130.88 ± 61.46, and posttherapy scores were 127.03 ± 60.59 with a difference of 3.84 ± 4.04, which was not significant; the HTS group initially had 113.98 ± 48.83 and a posttherapy score 101.61 ± 37.53 with a difference of 12.37 ± 16.22, which was significant. Durek et al.[139] found that the HTS improved both speed and accuracy of reading in a group of children with both a CI and reading problems compared with a control group. Previous studies have suggested that the minimal number of HTS therapeutic sessions needed to be greater than 8 to remediate a vergence defect.[26,124,125] One might wonder what the results would be had there been a longer period of therapy, i.e., 1 month, especially since the authors suggested that prism and HTS treatment yield similar results.

Current clinical guides for the treatment of symptomatic CI

Review of the literature currently supports a specific CITT protocol for in-office vision therapy with supplemental home therapy.[25,155,156] If office-based vision therapy is impractical because of cost, time constraints, and other factors, then home-based computer vision therapy using random dot stereograms (RDS) in an operant conditioning paradigm and push-up techniques can be prescribed.[25,156] The operant conditioning paradigm should be monitored on the Internet with frequent office visits to foster compliance. In addition, it is useful to supplement computer therapy with noncomputerized therapeutic techniques, such as pencil push-ups, Brock string, Lifesavers cards, stereoscopes, and loose prisms. Incorporation of "distractors," such as talking to the patient or having the patient move while doing therapy, may help to automate accommodative– vergence responses. When home-based computer vision therapy is prescribed, therapeutic results should be evaluated every month to evaluate progress and to emphasize the importance of treatment. Utilization of the symptoms questionnaire (CISS[117,118]) provides both the clinician and patient a scientifically validated method of monitoring symptoms before and after therapy.

Therapy includes 3 phases:1) normalization of accommodative and vergence amplitude and facility, 2) automation of accommodative and vergence function, and 3) sustaining of integrated accommodative–vergence function in the presence of distraction.[3] Vergence stimuli should initially be large in size and then systematically reduced in size.[40] Repetitive therapy performed for short periods each day seems to be more effective than therapy performed for the same amount of time in 1 day.[157] A variety of stimuli should be used to stimulate amplitudes, facility, and sustaining ability. Lastly, to improve reflexive accommodative/vergence responses, movement and other confounding stimuli should be added to therapy.

Each phase should take approximately 6 visits when combined with home reinforcement therapy. Patients often notice worsening of symptoms during the first few weeks of therapy. Rarely, they may even vomit from the exercises. Before therapy, the patient should be advised of the possibility of these adverse effects. After this period of increased discomfort, most patients begin to report that their symptoms disappear, concentration increases, and near vision tasks are easier. We advocate the integration of nonaccommodative/vergence tasks while doing therapy to improve automaticity. For example, have the patient perform a math task while altering vergence. The goal of therapy is to improve the automaticity of reflexive accommodative–vergence movements. The successful results found with office-based vision therapy may be related to the therapist interaction with the patient in developing reflexive accommodative–vergence. Description of therapy techniques may be found elsewhere.[109,113,116]

Summary

CI patients have reduced convergence that manifests itself through reduced convergence fusional amplitudes and an increased effort associated with convergence, significant exophoria at near, or receded near point of convergence. These patients usually manifest symptoms that may be detected with the CISS. The symptoms associated with accommodative–vergence anomalies are unique and may be differentiated from dry eye and other conditions. The intensity of symptoms in CI may be dependent on the amount and type of near work, degree of suppression, or sensitivity to pain.

The NEI/NIH CITT clinical trials were designed to determine the most effective treatment(s) for eliminating symptoms associated with CI. The treatment arms included office-based accommodative–vergence therapy with supplemental home therapy, placebo office-based vision therapy, home-based computerized vision therapy with pencil push-ups, and pencil push-ups. At the end of 12 weeks of therapy, treatment effects were assessed. In-office accommodative–vergence supplemented with home therapy was found to be the most effective treatment. Long-term effects were determined at 6 months and 12 months of follow-up and found to persist for each therapeutic treatment arm. If the CITT-defined gold standard of treatment is not available, then it is our opinion that the patient should be prescribed home-based computerized vision therapy with pencil push-ups.[25,156] Home-based computer vision therapy should be performed with follow-up, including monthly visits and printouts of performance or internet tracking to improve compliance. The clinician should incorporate a home training regimen that has some of the characteristics of office-based vision therapy, e.g., distractors. Effectiveness of therapy is judged by relief of symptoms, improvement of concentration and reading skills, and improved accommodative and vergence abilities. Future studies are needed to determine the effects of motivation and longer therapy.

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Appendix 1 CI Symptom Survey

Clinician instructions: Read the following subject instructions and then each item exactly as written. If subject responds with "yes," please qualify with frequency choices. **Do not give examples.**

Subject instructions: Please answer the following questions about how your eyes feel when reading or doing close work.

		Never	(not very often, Infrequently)	Sometimes	Fairly often	Always
1.	Do you 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 white reading or doing close work?					
15.	Do you have to re-read the same line of words when reading?					
		_× 0	_× 1	_× 2	_× 3	_× 4

Appendix 2

A detailed description of each procedure and the protocol used in the CITT study for each group is provided in the following site: *http://optometry.osu.edu/research/CITT/pdfs/MOP_Chapter08.pdf*. The CITT was made up of the following treatment arms:

Home-based pencil push-up therapy group

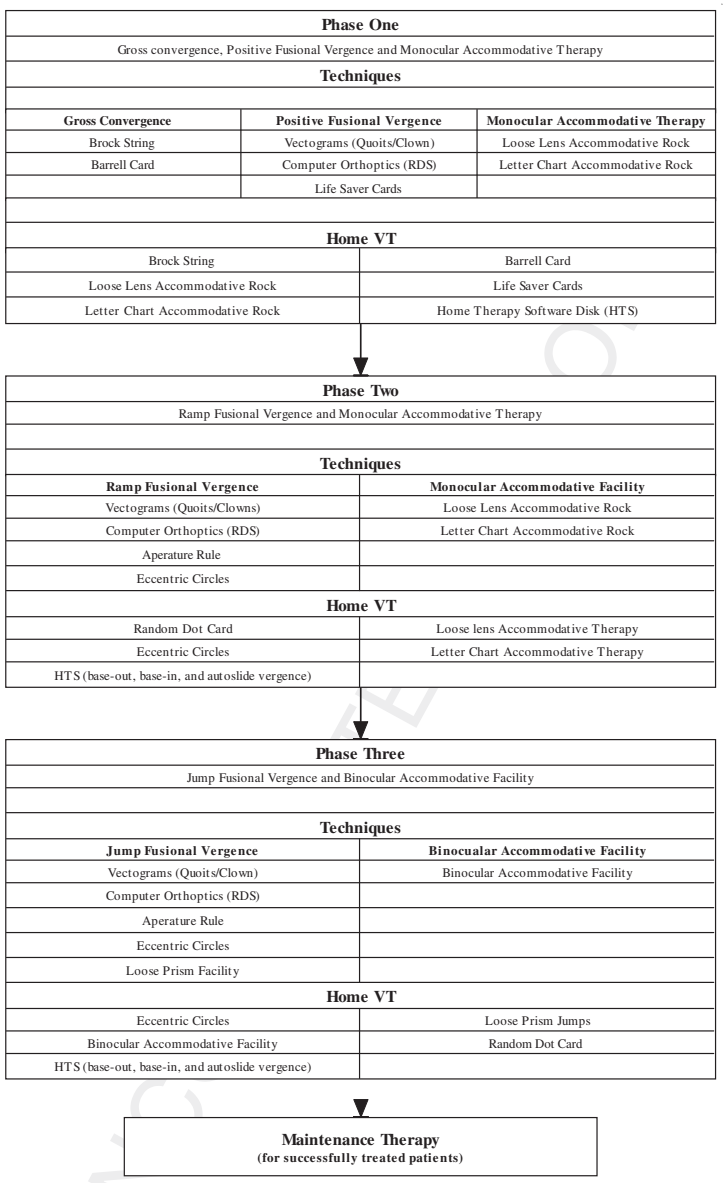
The home-based pencil push-up therapy utilizes a small letter on the pencil and an index card in the background to provide physiologic diplopia control. Although a physiologic diplopia control is not universally used in standard clinical practice, it has often been recommended in the literature [134,161] to ensure that the subject is not suppressing.

Home therapy group

The home-based vt/orthoptics group was asked to practice the same well-defined pencil push-up procedure as the home-based pencil push-up group. In addition, they were assigned the Home Therapy System computer software at home.[123] The HTS program was chosen because it is used by more optometrists and ophthalmologists than any other home vision therapy system because it uses scientific principals of operant conditioning with random dot stereograms, it is easy to use, and has performance graphs to monitor each session and weekly performances. Subjects were required to demonstrate their ability to perform these procedures to the therapist in the office before beginning therapy at home. Therapy required 20 minutes per day (15 minutes for HTS and 5 minutes for pencil push-ups).

In-office therapy group

Patients in the in-office therapy group had 12 weekly vision therapy sessions that included a multitude of accommodative and vergence activities. A summary of the protocol adopted by the CITT group is presented. In addition, patients assigned to the in-office protocol had home therapy, which included pencil push-ups and the HTS computer software.[161]



Phase 1	
Gross convergence	Endpoint
A. Brock string (level 1)	Converge to a bead 2.5 cm from nose
B. Brock string (level 2)	Voluntarily converge to a bead 2.5 cm from nose
C. Barrel card	Fuse each of the 3 beads, hold fusion for 5 seconds, for 10 repetitions
Vergence	Endpoint
D. Vectograms (quoits/clown) base-out	30^{Δ} Base-out
E. Computer orthoptics (RDS) base-out	45^{Δ} Base-out with large, medium, small RDS targets
F. Lifesaver cards	Able to clear all 4 levels of difficulty and hold fusion for at least 5 seconds
Accommodation	Endpoint
G. Loose lens accommodative rock	Clear +1.50/-3.00, 10 cycles per minute
H. Letter chart accommodative rock	Clear near chart at age-appropriate distance and be able to clear to distance chart
Phase 2	
Vergence	Endpoint
I. Vectograms (quoits/clown)	25^{Δ} Base-out, 12^{Δ} Base-in (letter "L")
J. Computer orthoptics (RDS)	45^{Δ} Base-out with large RDS targets 15^{Δ} Base-in with large RDS targets
K. Aperture rule	30^{Δ} Base-out (card 12), 15^{Δ} Base-in (card 6)
L. Eccentric circles	30^{Δ} Base-out/ 15 base-in
Accommodation	Endpoint
M. Loose lens accommodative rock	Clear +2.00/-6.00, 10 cycles per minute
N. Letter chart accommodative rock	Clear near chart at age-appropriate distance, change fixation and clear far letter chart at 3 m for 10 cycles per minute
Phase 3	
Vergence	Endpoint
O. Vectograms (quoits/clown) jump vergence	Alternately fuse 25^{Δ} base-out and 15^{Δ} base-in for at least 10 cycles per minute
Computer orthoptics (RDS) jump vergence	Alternately fuse 45^{Δ} base-out and 15^{Δ} base-in
Q. Aperture rule jump vergence	Using 8^{Δ} base-out/4^{Δ} base-in prism flippers, achieve clear, single binocular vision with card 8 for convergence (28^{Δ} Base- out to 16^{Δ} base-out) and card 4 for divergence (2^{Δ} base-in to $14^{\Delta b}$Base-in) for 10 cycles per minute
R. Eccentric circles jump vergence	Regain clear, chiastopic fusion after fusion is disrupted with a card separation of 12 cm (30^{Δ} base-out) and clear, orthopic fusion with a card separation of 6 cm (15^{Δ} Base-in). Switch between chiastopic and orthoptic fusion with the cards held 6 cm apart for 20 repetitions
S. Loose prism facility	For jump vergence, achieve single, clear, binocular vision while viewing a 20/30 target at 40 cm though 25^{Δ} base-out and then without prism for at least 10 cycles per minute. For jump divergence, achieve single, clear, binocular vision while viewing a 20/30 target at 40 cm through 12^{Δ} base-in and then without prism for at least 10 cycles per minute.
Accommodation	Endpoint
T. Binocular clear vision while viewing 20/30 point at 40 cm through +2.00 and alternately −2.00 for at least 13 cycles per minute without suppression.	Single, accommodative facility