Convergence Insufficiency and Vision Therapy

Ching Yan Simon, SZE

Abstract: *Convergence insufficiency (CI) is a prevalent binocular vision disorder at near. Study showed a special relationships between symptoms and clinical signs in patient with CI. Even though, pencil push-ups alone is the most commonly prescribed treatment by both ophthalmologists and optometrists for young patients with symptomatic CI, whereas , office-based vision therapy with home training was found to be the most effective treatment in those CI. FMRI studies have shown the clinical implications for understanding the behavioral and neurophysiological changes in patients performed office based vision therapy with home training that resulted in a sustained reduction in CI symptoms. Moreover, study indicated that the concussion-related convergence insufficiency treatment outcome was successful or improved in most of the subjects.*

1. Introduction

Convergence Insufficiency (CI) is a binocular vision disorder first described by von Graefe in 1855 and later elaborated by Duane in 1886. Patient with CI always encounter eye strain, eye tired, more technical speaking, namely asthenopia, which is a tiredness of the eyes caused by prolonged close work with an undiagnosed or uncorrected vision problem. The symptoms also included unstable, blurred or even double vision, and headaches when engaged in reading or at near task. Losing place, losing concentration, burning sensation, epiphora, and feeling sleeping after a short period of reading or near task, which can deteriorating with time,are frequently reported.

CI is typically characterized in recent studies by the following signs. First, exophoria that is greater at near than distance. Second, a reduced near point of convergence (NPC), i.e., a breakdown in convergence greater than 3 inches, Third, a reduced positive fusional convergence (PFC) at near. However, not all patients are symptomatic.

In the past decades, there was a high variability in the prevalence of CI which could be attributed to differences in the definitions of CI, the differences in the study protocols, and inadequate population-based studies. Consensus regarding the most effective treatment is lacking.

In the past studies from 1998 had started to provide scientific evidence to support and define the criteria and validity of CI. By members of the CITT Study Group, Rouse et al. (1999) had found a higher prevalence of CI in children than had been previously assumed. Fifth and sixth graders were screened to define and determine both the presence and severity of CI. These children were classified according to the presence and number of the clinical signs found. Twenty-one percent demonstrated different 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. The prevalence of CI became clearer after the large-scale randomized clinical trials.

Borsting E. et al. (2003) was found the 55% of patients had no signs of CI; 33% had one sign; 12% had 2 signs; and 6% had all 3 signs. 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.

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 new scientific based Vision therapy, some inclusive and exclusive criteria are needed to establish new milestones. From my observation, there is a strong familial tendency in CI, even though there are no studies reporting the incidence of CIs in families.

2. Definition

The definition is of the vital foundation for the research on the validity of vision therapy in CI. CI is typically characterized as a syndrome of clinical signs. Rouse (1998, 1999) defined CI in a standardized by the signs of greater exophoria at near, a receded near point of convergence (NPC), and reduced positive fusional vergence (PFV) at near vision. And reported that children having all three clinical signs of CI 1.) Exophoria at near vision, 2.) Receded NPC and 3.) Reduced PFV are more symptomatic than children who exhibit only one or two of the clinical signs.

Borsting (2003) concluded that adults with symptomatic CI had a significantly higher Convergence Insufficiency Symptom Survey (CISS) score than adults with normal binocular vision. The results of the study demonstrate that the CISS was a valid and reliable instrument that could be used clinically or as an outcome measure for research studies of adults with CI.

Convergence Insufficiency Treatment Trial Investigator Group (2008) implemented pilot studies and large scale randomized Convergence Insufficiency Treatment Trial (CITT) started to Convergence Insufficiency Symptom Survey (CISS) score as the primary outcome, and the inclusive signs of CI in different severity as the second outcome.

For the current validity of vision therapy in CI, Rouse and Convergence Insufficiency Treatment Trial Investigator Group (2009) concluded that the CISS continued to be a valid instrument for quantifying symptoms in 9 to <18 year-old children and these results confirmed the validity of a cut

-point of ≥ 16 in distinguishing children with symptomatic CI from those with normal binocular vision (NBV).

On the other hand, Cohen et al (2010) found the asthenopic symptoms score was correlated with convergence amplitude , which indicated a modest correlation between symptoms and clinical signs of CI (NPC, exophoria at near and PFV), but they did not classify the severity of the CI. Later after that, a study had shown the association between the severity of symptoms and the clinical signs in CI. Research and study on neurological association or change after vision therapy of CI have been done later.

Prevalence

Convergence insufficiency (CI) was also a well-known syndrome of binocular visual dysfunction at near work. Those symptoms have been mentioned previously. Daum (1988) reviewed the past studies, and found that there were considerable variation was noted in the criteria used to define the CI condition. With the well definition of CI, the prevalence of CI was become more consistent among different studies in the further researches.

Rouse MW et al. (1988) found that the clinically significant CI with inclusion criteria receded
NPC =or >7.5cm was identified in 17.6% of the 8-12 years old children. Rouse MW et al. (1999) suggested that CI, which defined as high suspect and definite, was frequent of 13% among fifth and sixth grade children aged 11-12 years old. The frequency of AI increased with the number of CI-related signs. And it concluded that those definite CI children with three signs, 78.9% of them were suffered AI. The children were classified as accommodative insufficiency (AI) if they failed Hofstetter's minimum amplitude formula or had greater than a + 1.00 D lag on Monocular Estimate Method retinoscopy". In addition, Borsting (2003a) found that among 392 children aged 8 to 15 years in school, 4.6% of them had three signs of CI, 12.7% had two signs of CI, 10.5% were classified as AI but without signs of CI.

In the past studies reported only 2.2-8% of school children population only having CI. On the other hand, all the studies agreed that CI and AI were common conditions in school-age children and are associated with increased symptoms.

Cooper (2012) pointed out that Convergence insufficiency was a common binocular vision disorder affecting around 5% of the population in the United States. Whereas, Jang JU and Inn-Jee Park. (2015) adopted the 3 clinical signs inclusion criteria for definite CI; they still found a higher prevalence of Convergence insufficiency in the rural area of Korea, which was 10.3% in 583 school children. Jang JU, Jang JY, Tai-Hyung K, and Moon HW. (2017) found that the prevalence of symptomatic CI was 13.6 % in 235 elementary school children in Korea, aged about 8-12 years in another research,. It seems that that there is a geographic difference in symptomatic CI. Further studies are necessary in Asian population.

3. Background clinical signs and symptoms

All three randomized clinical trials laid the milestone and landmark for the further studies in convergence insufficiency.

3.1 Symptoms

Borsting EJ et al. (1999) suggested that the CIRS symptom survey was a valid instrument for differentiating CI children from those with normal binocular vision.

Symptomatic CI Symptom Survey Score had been modified from 13 question version ≥ 9 in pilot study to 15 question version ≥16 in large-scale randomized clinical trials in young school children. The validity of CISS was established in 2003, derived from CIRS symptom survey. For the students from 9-18 years of age, Borsting, Convergence Insufficiency Treatment Trial (CITT) Group et al.(2003b) found those results below: Good discrimination (sensitivity, 96%; specificity, 88%) was obtained using a score of > or =16. The results of the study indicated that the CISS was a valid and reliable instrument to use as an outcome measure for children aged 9 to 18. The study concluded that these results confirmed the validity of a cutoff point of ≥ 16 in distinguishing children with symptomatic CI from those with normal binocular vision (NBV).

Rouse MW and CITT group et al. (2004) found that adults aged 19-30 with symptomatic CI had a significantly higher CISS score than adults with NBV. The results of the study demonstrated that the CISS was a valid and reliable instrument that can be used clinically or as an outcome measure for research studies of adults with CI. Good discrimination (sensitivity = 97.8%, specificity = 87%) was obtained using a score of 21 or higher which was different from the cut point of student aged 9-18.

In addition, Rouse and CITT group et al. (2009) reported a confirmatory study of the validity of CISS. Barnhart C and CITT study group et al. (2012) further analyzed with CISS into eye-related and performance-related symptoms. Performance-related symptoms (e.g., difficulty concentrating when reading or studying) were reported more frequently than eye-related symptoms prior to treatment. In fact, the 6 most frequently reported symptoms were all performance-related items. It indicated children with symptomatic CI report performance-related symptoms more frequently than eye-related symptoms, whereas eye-related symptoms were interestingly more frequently reported than performance-related symptoms in Adults over 18 years old; a targeted history such as the CISS that addresses both performance- and eye-related symptoms is recommended.

Children with parent-reported ADHD were more symptomatic CI than those without parent-reported ADHD. A new direction of future study regarding the relationship of CI and symptoms and their potential influence on ADHD with professional diagnosis, reading performance, and attention was needed.

3.1.1 Classification of Symptom Level

Borsting EJ et al. (2003) Children with CI showed a significantly higher CISS symptom score than children with normal binocular vision. The results of the study indicate that the CISS is a valid and reliable instrument to use as an outcome measure for children aged 9 to 18. Good discrimination (sensitivity, 96%; specificity, 88%) was obtained using a score of $>/=16$.

Bade A. et al. (2013) defined the severity of symptom level. All of these children were symptomatic with a CISS score $\geq$ 16. The cut-points for the level of symptoms were classified as Mild when the $\leq$33rd percentile or a CISS score $\leq$24, Moderate when >33rd percentile to < 67th percentile or CISS scores ranging from 24.5 to 34) and, Severe when $\geq$67th percentile or a CISS score >34. In these studies, CISS scores ranged from 16 as the least symptomatic to 60 as the most symptomatic.

3.2 Clinical Signs of Convergence Insufficiency

According to Scheiman M Wick B (2002) *Clinical management of binocular vision* LWW.p4-5., the binocular diagnostic tests for the clinical signs are as follows:

Distance and near visual acuities, and routine subjective and objective refractions.

Measurement of the phoria by Von Graefe phoria test,

Modified Thorington test, Fixation disparity test,

Gross convergence (NPC), monocular amplitude of accommodation,

Direct measures includes smooth vergence testing (PFV and NFV), step vergence testing, vergence facility testing,

Indirect measures includes Positive Relative Accommodation (PRA), Negative Relative Accommodation (NRA), monocular and binocular accommodative facilities (MAF and BAF), Monocular Estimate Method (MEM),

Sensory status indicated in stereopsis testing preferably with Random dot, and Worth four-dot test, Cycloplegic refraction would measure if necessary.

3.2.1 Classification of Severity of Clinical Signs

There were no published age-related normative for Near point of convergence values in the literature to diagnose convergence insufficiency. Until Hayes GJ et al (1988) reported a supporting study using a random sample of clinic patients aged 10-12 years and suggested that patients with NPC breaks > 6 cm were more than twice as likely to be symptomatic than patients with NPC breaks < or = 6 cm. A clinical cutoff value of 6 cm was advised for patients of elementary school age.

A concrete definition of convergence insufficiency started to adopt in large scale studies.

Rouse et al. Convergence Insufficiency and Reading Study (CIRS) group (1999), the former CITT group adopted

unanimous inclusion criteria recruited 684 Childs as subjects.
1) An exodeviation at near at least 4Δ greater than at far,
2) Insufficient PFV at near (PFV $\leq$15Δ base-out blur or break or failing Sheard's criterion [PFV less than twice the near phoria]),
3) A receded NPC break (6 cm or greater),
4) A symptom score of $\geq$16 on the CISS.

Alder (2002) agreed CI was defined as NPC of 10 cm or greater (either with or without the presence of asthenopic symptoms for near work) accompanied by exophoria greater at near than at distance. It concluded that the office based vision therapy was effective in treating CI symptoms.

As quoted by Bade A. et al. (2013):
"Each sign of CI was classified as mild, moderate or severe based on means and standard deviations (SD) from previously published normative studies. For near exophoria, cut-points for mild were $\leq$ 8 exo ($\leq$1SD), moderate >8 exo to <13 exo (>1SD to < 2SD), and severe $\geq$13 exo ($\geq$2SD). For PFV, cut-points for mild were $\geq$ 15Δ ($\leq$ 1SD), moderate >7Δ to <15Δ (>1SD to <2SD), and severe $\leq$7Δ ($\geq$2SD). For NPC, the cut-points were mild 6 cm to <9 cm ($\geq$1SD to <2SD), moderate 9 cm to <12 cm ($\geq$2SD to <3SD), and severe $\geq$12 cm ($\geq$3SD). For Sheard's criterion, normative data to establish cut-points were not available. Therefore, we divided the range of findings into three levels. A mild deficit was considered to be PFV $\geq$ 1.5 $\times$ near phoria, a severe deficit was PFV < near phoria, and a moderate deficit was values in between these ranges".

Bade A. et al. (2013) found that mean CISS scores were not significantly different between those with mild, moderate or severe clinical signs. Moreover, the percentage of subjects with higher levels of symptoms did not increase as the clinical signs became more severe. They concluded that among symptomatic children with a CISS score $\geq$ 16 and three clinical signs of CI, there was no further association between the severity of the clinical signs and their level of symptoms.

And now, we have a better understanding about the association between the clinical signs of CI and the patient's level of symptoms. There seemed to have a plateau of CISS score of visual symptoms. Once the CISS score reached 16 or more, the increase in CISS scores was not associated with the severity of those 3 clinical signs.

They suggested explanation that when there was as exophoria increases and/or as convergence ability worsened, some subjects could either develop suppression or avoid near activities to reduce or eliminate visual symptoms.

3.3 Differential Diagnosis: CI and AI

3.3.1 Associated with accommodative dysfunction.

Accommodation system is cross-linked with vergence system. Once accommodation is initiated, it will trigger the vergence, known as accommodation convergence. The extent of accommodation to makes the vergence to be

changed is denoted as accommodative convergence to accommodation ratio (AC/A ratio), whereas, vergence leads to accommodation in another situation. The extent of vergence to direct the accommodation to be active is denoted as convergence accommodation to convergence ratio (CA/C ratio). So both systems are working in an interweaving way that one may be secondarily affected by another if one system is insufficiency or insufficiency. This is why the symptomatic patient with AI or CI exhibits the similar visual symptoms.

Rouse et al. (1999) pointed out that children were classified as accommodative insufficiency (AI) if they failed Hofstetter's minimum amplitude formula or had greater than a + 1.00 D lag on Monocular Estimate Method retinoscopy. The frequency of AI increased with the number of CI-related clinical signs. For those CI children with three clinical signs, 78.9% were classified as also having AI and concluded there were a high percentage of CI children with an associated AI.

Borsting et al. (2003) found 10.5% were classified as AI (with no signs of CI) CI in 392 participated in testing for CI and AI. Moreover, concluded that CI and AI were common conditions in school-age children and were associated with increased symptoms.

Scheiman M et al. (2006) found that accommodative insufficiency was the primary source of symptoms in children diagnosed with convergence insufficiency. Study questioned the accuracy of another study's conclusion that "high visual symptom scores for children with CI were the result of the presence of AI" and that children with CI only "are not significantly more symptomatic than children with normal binocular vision."

Convergence Insufficiency Treatment Trial Study Group (2008) found that among those 221 participants, 55% of the children were associated with accommodative insufficiency even though they were included in the diagnostic criteria of CI.

Martínez et al. (2014) study suggested using the accommodative amplitude and monocular accommodative facility for diagnosing accommodative insufficiency and a high positive relative accommodation for accommodative excess.

3.4 Etiology in Convergence Insufficiency

It was known that most of the patients with convergence insufficiency were idiopathic. However, majority of patients with CI suffered concomitant ocular and neurologic anomalies. There were no evidence proved that CI was of either psychogenic origin or psychological etiology.

What we could found was that symptomatic CI was resulted from a breakdown of accommodative convergence cross-link from accommodative anomalies, fusional convergence or voluntary convergence interactions. The primary problem was slow adaptive vergence, not the assumed fast vergence that binocular vision at near was breakdown, causing ocular asthenopic symptoms in patients with CI.

From the review by Cooper (2012), there were numerous possible causes of convergence were listed. Primary causes were developmental delay, poorly developed accommodation or convergence, wide interpupillary, presbyopia, endocrine disorders, anxiety and toxemia.

Convergence insufficiency was also secondary to systemic disorders, concussion, traumatic brain injury (TBI), cerebral vascular accidents (CVA), encephalitis, Anoxia, smoking, drug intoxication, malnutrition, debility, hepatitis and mononucleosis.

CIs were associated in some patients with ocular motor disturbance or binocular anomalies, e.g. Duane's syndrome. The patients with Graves's disease and early thyroid-related eye disease reported ocular motor problems, especially CI.

Moreover, it has been observed that CI were found in Parkinson's disease and left middle cerebral artery occlusion.

Some decompensated exophoria found after eye surgery, such as cataract, LASIK or other refractive treatment may have a gross convergence insufficiency.

Loss of amplitude of accommodation in large exophoria and presbyopic patients without a compensating slow adaptive vergence mechanism could manifest convergence insufficiency due to the changes in accommodative and convergence linkage.

It seems that CI is multi-factorial origin that any factor affects the brain function will caused in problem at near manifested as asthenopic symptoms.

4. Experimental design: 4 golden standard Randomized double blind clinical trials

Recently, the researches and studies had developed golden standard Randomized double blind pilot studies and clinical treatment trials as the milestones for the concrete and scientific evidence basis of Vision therapy in treating Convergence insufficiency symptoms and clinical signs.

In 2005, three pilot studies in which two were done for school age children. One was done for young adult. Scheiman M. And CITT group et al (2005a, 2005b), run a randomized clinical trial of treatments study, triggered vigorous noise and responses from other eye care discipline.

Scheiman M. And CITT group et al (2005a):
In this pilot study, the primary outcome measure was the symptom score on CISS. Secondary outcome measures were the near point of convergence and positive fusional vergence at near. The results showed that only patients in the vision therapy group demonstrated statistically 42% improvement in symptoms and clinically significant changes in the near point of convergence and positive fusional vergence at near. This laid a concrete milestone for large-scale randomized clinical treatment trials.

Scheiman M. And CITT group et al (2005b):
In a randomized clinical trial, 72 children aged 9 to <18 years with symptomatic CI were assigned to either base-in prism glasses or placebo reading glasses. Symptom level, measured with a quantitative symptom questionnaire CISS, which was the primary outcome measure. Near point of convergence and positive fusional vergence at near were secondary outcomes. They suggested that the placebo effect was the reason for the decrease in symptoms found in the base-in prism reading glasses group. In addition, the treatment effect might be different in adults group.

The third one was also done in (2005c) for young adults. The purpose of this article was to compare vision therapy/orthoptics, pencil pushups, and placebo vision therapy/orthoptics as treatments for symptomatic convergence insufficiency in adults 19 to 30 years of age.

Scheiman M. And CITT group et al (2005c):
In this study, the primary outcome measure was the symptom score with the cut-point < 21 on the CISS which was different from the score < 16 used in schoolchildren. Secondary outcome measures also were the near point of convergence and positive fusional vergence at near.

Inclusion criteria and Exclusion criteria were similar in those randomized studies. Inclusion criteria: Age 9 to <18 years, best corrected visual acuity of 20/25 or better in both eyes at distance and near. Accept to wear eyeglasses to correct refractive error if necessary. Exophoria at near with 4 Δ or greater than at far. Insufficient positive fusional convergence at near (fails Sheard's criterion).Insufficient positive fusional convergence at near (fails Sheard's criterion). Receded near point of convergence with 6 cm break. Able to see 500 seconds of arc on the forms part of the Random dot Stereo-test. CI Symptom Survey-V15 score. Informed consent and willingness to participate in the study and would be randomized.

Exclusion criteria: CI previously treated with prism, pencil pushups, or office based vision therapy/orthoptics (no more than 2 months of treatment within the past year). Amblyopia, constant strabismus, history of strabismus surgery, anisometropia >1.50 D (spherical equivalent) difference between eyes. Previous refractive surgery. Vertical heterophoria greater than 1 Δ. Systemic diseases known to affect accommodation, vergence, and ocular motility such as multiple sclerosis, Grave's thyroid disease, myasthenia gravis, diabetes, and Parkinson's disease. Systemic diseases known to affect accommodation, vergence, and ocular motility such as multiple sclerosis, Grave's thyroid disease, myasthenia gravis, diabetes, and Parkinson's disease. Any ocular or systemic medication known to affect accommodation and/or vergence. Monocular accommodative amplitude, which was less than 4 D in either eye, measured by the push up method. Manifest or latent nystagmus. Attention deficit hyperactivity disorder or learning disability diagnosis by parental report that, in the investigator's opinion, would interfere with treatment.

The primary outcome measure was the symptom score on the Convergence Insufficiency Symptom Survey. Secondary outcome measures were the near point of convergence and positive fusional vergence at near. The conclusion in this pilot study was that vision therapy/orthoptics was more effective than pencil push-ups or placebo vision therapy/orthoptics in reducing symptoms and improving signs of convergence insufficiency in children 9 to 18 years of age. Both pencil push-ups and placebo vision therapy/orthoptics was not effective in improving either symptoms or signs associated with convergence insufficiency.

The fourth one, a large-scale clinical treatment trial was done in 2008. Convergence Insufficiency Treatment Trial Study Group (2008a, 2008b) conducted a first large-scale golden standard randomized clinical treatment trial with 221 children aged 9 to 17 years with symptomatic convergence insufficiency, were assigned to 1 of 4 treatments.

1. home-based pencil push-ups (HBPP), 2. Home-based computer vergence/accommodative therapy and pencil push-ups (HBCVAT+), 3. Office-based vergence/accommodative therapy with home reinforcement (OBVAT), 4. Office-based placebo therapy with home reinforcement (OBPT).

This study completed in 2008, known as the CITT demonstrated that office-based vision therapy was significantly more effective than home-based vision therapy and concluded that it should be the primary treatment for the clinical signs and visual symptoms in children with CI.

Table 1: Procedures and sequence of work in the treatment of CI with vision therapy. The Convergence Insufficiency Treatment Trial (CITT) Study Group. (2008b)

Phase 1: Gross convergence, positive fusional vergence and monocular accommodative therapy	
Techniques in consultation	**Home Vision therapy**
Gross convergence: Brock string Barrel card	Brock string Barrel card
Positive fusional vergence: Vectograms (Quoits/clown) Computer orthoptics (RDS) Life Saver cards	Life saver cards Computer Home therapy (HTS)
Monocular accommodative amplitude: Loose lens accommodative rock Letter chart accommodative rock	Loose lens accommodative rock Letter chart accommodative rock
Phase 2: Ramp fusional vergence and monocular accommodative therapy	
Techniques in consultation	**Home Vision therapy**
Fusional vergence ranges:	

Vectograms (Quoits/Clown) Computer orthoptics (RDS) Aperture Ruler Eccentric circles	Eccentric circles Randot Dot card HTS(Base-OUT, Base -IN, and Autoslide vergence)
Monocular accommodative facility: Loose lens accommodative rock Letter chart accommodative rock	Loose lens accommodative rock Letter chart accommodative rock
Phase 3: Jump Fusional Vergence and Binocular Accommodative Facility.	
Techniques in consultation	**Home Vision therapy**
Jumpm Fusional Vergence: Vectograms (Quoits/Clown) Computer orthoptics (RDS) Aperture Ruler Eccentric circles Loose prisms Facility	Eccentric circles Loose prisms jumps Randot dot card HTS(Base-OUT, Base -IN, and Autoslide vergence)
Binocular Accommodative Facility: Binocular Accommodative Facility	Binocular Accommodative Facility

The fourth one was that CITT-ART Investigator Group et al (2015) commenced a new Convergence Insufficiency Treatment Trial – Attention and Reading Trial (CITT-ART).

The study was still on-going. The long-term effects of treatment would be assessed 1 year after treatment completion. The final results could contribute to a better understanding of the relationship between the treatment of symptomatic CI and its effect on reading and attention. This large scale study not only developed for the sensorimotor recalibration in visual teaming, tracking, and focusing skills, but also another ground break evidence to neurological effect by vision therapy.

Study Strengths in CITT-ART:
The CITT-ART was the first randomized clinical trial designed to evaluate the effect of successful treatment of symptomatic CI in children on reading and attention. Study strengths included a multi-disciplinary group of investigators. The one-year follow up will allow us to determine if OBVAT has a long-term effect on reading and attention.

The results of the study will facilitate to a better understanding of the critical link between CI and reading and attention. This guided the development of other scientific investigations regarding the relationships between visual dysfunctions and other developmental disorders in children.

5. Treatment and Outcome Measures

There was a lack of consensus regarding the most appropriate treatment for convergence insufficiency (CI). Several treatments were commonly prescribed including vision therapy, base-in prism reading glasses, and home based pencil push-ups.

5.1 Vision therapy

In Convergence insufficiency Treatment Trial (CITT), during 12 weeks of treatment, the primary outcome measure was the symptom score on the Convergence Insufficiency Symptom Survey (CISS). Secondary outcome measures were the near point of convergence and positive fusional vergence at near.

Scheiman M. and CITT group et al (2005a,2005b,2005c) Symptoms scores CISS were significantly reduced from 32.1 to 9.5 in the vision therapy/orthoptics group but not in the pencil push-ups group with symptom score decreased from 29.3 to 25.9 or placebo vision therapy/orthoptics group. Only those patients in the vision therapy/orthoptics group demonstrated both statistically and clinically significant changes in the clinical measures of near point of convergence from 13.7 cm to 4.5 cm and positive fusional vergence at near from 12.5 prism diopters to 31.8 prism diopters.

Convergence Insufficiency Treatment Trial Study Group (2008a, 2008b) reported " the office-based vergence/ accommodative therapy with home reinforcement (OBVAT) group's mean Convergence Insufficiency Symptom Survey score (15.1) was statistically significantly lower than those of 21.3, 24.7, and 21.9 in the home-based computer vergence/accommodative therapy and pencil push-ups (HBCVAT+), home-based pencil push-ups (HBPP), and office-based placebo therapy with home reinforcement (OBPT) groups, respectively. The OBVAT group also demonstrated a significantly improved near point of convergence and positive fusional vergence at near when compared with the other groups. A successful or improved outcome was found in 73%, 43%, 33%, and 35% of patients in the OBVAT, HBPP, HBCVAT+, and OBPT groups, respectively".

Scheiman M.et al (2009) reviewed that Office-based vergence/accommodative therapy (OBVAT) was significantly more effective than home-based or placebo therapies. Base-in prism reading glasses were no more effective than placebo reading glasses for the treatment of symptomatic CI in children. Those recent CITT in 2005 and 2008 showed that office-based vision therapy success rate was 75%, resulting in normal or significantly improved visual symptoms and clinical signs.

Scheiman M. et al. (2010) reported that the rate of improvement was more rapid for clinical signs (NPC and PFV) than for symptoms in children undergoing treatment for CI. The treatment of OBVAT resulted in a more rapid improvement in symptoms, NPC and PFV, and a greater amount of patients reaching the criteria of success when compared with HBPP, HBCVAT+, or OBPT.

CITT-ART Investigator Group et al. (2015) conducted a new Convergence Insufficiency Treatment Trial – Attention and Reading Trial (CITT-ART). Jang et al. (2017) also had the same protocol as CITT study with office-based vergence/accommodative therapy with home reinforcement (OBVAT). It reported that the average near point of convergence, negative relative accommodation and positive relative accommodation improved, increasing near positive fusional vergence and decreasing exophoria. Their results suggested that vision therapy-OBVAT was very effective to recover from symptomatic convergence insufficiency.

A new measure of Vision therapy by fMRI correlated the cortical improvement in the pre and post treatment. Objective measures of the Convergence and divergence in 4° step responses were newly adopted to test and compare between control adult subjects and CI adult subjects in Alvarez TL et al. (2010) study. It found that the convergence peak velocity was significantly slower in CI subjects compared with control subjects. Neural correlates of the CI subjects were quantified with functional magnetic resonance imaging scans before and after vision therapy with the significantly improved clinical signs and symptoms. Furthermore, clinical parameters, the positive fusional vergence, and average peak velocity from 4° convergence steps significantly increase with the functional activity within the frontal areas, cerebellum, and brainstem.

Scheiman M et al. (2017) conducted a pilot study for the evaluation changes in objective measures of disparity vergence after office-based vision therapy (OBVAT) for concussion-related convergence insufficiency (CI). The primary and objective outcome measure was average peak velocity for 4° symmetrical convergence steps. Other objective outcome measures of disparity vergence included time to peak velocity, latency, accuracy, settling time, and main sequence.

This was the first study of using objective measures of disparity vergence as outcome measures for concussion-related convergence insufficiency. These measures provided solid and ground -breaking information that was not accessible with routine clinical tests, about underlying physiological mechanisms leading to changes in clinical findings and symptoms.

5.2 Base- IN prism reading glasses

There was no consensus about the best method for prescribing prism for patients with CI. The prescription of base-in prismatic compensation glasses was used to reduce the demand of positive fusional convergence in some optometric and ophthalmology practices.

Scheiman M. et al (2005b) reported that " Base-in prism reading glasses were found to be no more effective in alleviating symptoms, improving the near point of convergence, or improving positive fusional vergence at near than placebo reading glasses for the treatment of children aged 9 to <18 years with symptomatic CI. The amount arf compensating prism was based on Sheard's criterion". It is because the prism adaptation or slow adaptive vergence occurred after a short period time in young adults. The substitution of disparity driven fusional vergence for accommodative convergence was trained to reduce the demand on the adaptive vergence system and relieved the patient's asthenopic symptoms and headache.

5.2.1 Primary outcome measure: CI Symptom Survey score

There were statistically significant changes in the mean CI Symptom Survey score in both the base-in prism group and placebo group. The CI Symptom Survey score decreased to less than 16 in either the base-in prism group or the placebo group was not substantial. The difference of CISS score between those two groups was not statistically significant. The relationship between amount of prism prescribed and CISS score was not correlated.

5.2.2 Secondary outcome measures

There were no clinically significant changes in either near point of convergence or positive fusional vergence at near. Few patients in either group achieved a normal near point of convergence or positive fusional vergence at near.

However, BI prism compensation was widely using in high addition presbyopic patients. Especially, the high exophoria in elderly as a result of age-related loss of accommodation secondary to the accommodation-convergence linkage, the BI prism became a corrective lens in the ocular misalignment at distance and at near.

BI prism compensation would suggest to patient if Vision therapy was not effective in relieving patient's symptoms.

5.3 Home based Pencil push-ups

Scheiman M and the CITT group (2005a, 2005c) compare vision therapy/orthoptics, pencil pushups, and placebo vision therapy/orthoptics as treatments for symptomatic convergence insufficiency in children 9 to 18 years of age and adults 19 to 30 years of age with symptomatic Convergence insufficiency:

In adult pilot study, vision therapy/orthoptics was the only treatment that produced clinically significant improvements in the near point of convergence and positive fusional vergence. However, over half of the patients in this group (58%) were still symptomatic at the end of treatment, although their symptoms were significantly reduced.

5.4 Botulinum toxin type A

The use of botulinum toxin type A for treating strabismus was first reported in 1980 by Scott. The principle was that the toxin produced a partial chemical denervation of the muscle, which lasts for 3 months, resulting in a localized reduction in lateral muscle activity.

As a whole, researchers found statistically significant changes in near point of convergence, positive fusional vergence and Convergence Insufficiency Symptoms Survey (CISS) for patients with CI, and in accommodative amplitude and CISS in patients with AI.

6. Efficacy of treatments in CI

Adler P. (2002) reported that the effect of treatment on a clinical sign - NPC was highly significant and the CI symptoms were significantly reduced after a longer treatment period which was not specified. The success rates seemed higher than reported by other studies. Post-treatment values <6.5 cm of NPC was 80.4%. But this was not so convincing that it was not a large scale and randomized clinical trial.

In this pilot study, Scheiman M., Convergence Insufficiency Treatment Trial Study Group et al. (2005a) found that vision therapy/orthoptics was more effective than pencil push-ups or placebo vision therapy/orthoptics in reducing symptoms and improving signs of convergence insufficiency in children 9 to 18 years of age. Neither pencil push-ups nor placebo vision therapy/orthoptics was effective in improving either symptoms or signs associated with convergence insufficiency.

Scheiman M., Convergence Insufficiency Treatment Trial Study Group et al. (2005b) concluded that Base-in prism reading glasses were found to be no more effective in alleviating symptoms, improving the near point of convergence, or improving positive fusional vergence at near than placebo reading glasses for the treatment of children aged 9 to <18 years with symptomatic CI.

Scheiman M., Convergence Insufficiency Treatment Trial Study Group et al. (2005c) conducted a randomized controlled double masked study. Patients in all three treatment sets demonstrated statistically significant improvement in visual symptoms with 42% in office-based vision therapy/orthoptics, 31% in office-based placebo vision therapy/orthoptics, and 20% in home-based pencil push-ups achieving a CI symptom score <21.

Convergence Insufficiency Treatment Trial Study Group (2008) in a recent placebo-controlled and randomized multi-center clinical trial the CI Treatment Trial (CITT) study recruited a total of 221 children with symptomatic CI were evaluated. The experimental group had underwent 12 weeks of Vision therapy demonstrated significant improvement of symptoms and clinical signs of near point of convergence (NPC) and positive fusional vergence (PFV) measures.

Glasses with prismatic correction may reduce the symptoms but do not treat the underlying condition. Scheiman M et al., The CITT study group. (2009) in a prospective study pointed out that office-based vergence/accommodative therapy was significantly more effective than home-based or placebo therapies. Base-in prism reading glasses were no more effective than placebo reading glasses for the treatment of symptomatic CI in children.

He further concluded recent clinical trials that office-based vision therapy was successful in about 75% of patients (resulting in normal or significantly improved symptoms and signs) and was the only treatment studied which was more effective than placebo treatments for children with symptomatic CI. He advised those eye care practitioners who did not currently offer this treatment could consider referring these patients to other optometrists who provides this treatment or consider expanding the treatment options available within their practice to manage CI condition.

Scheiman M et al. (2010) evaluated the kinetics of change in symptoms and signs of convergence insufficiency (CI) during 12 weeks of treatment with commonly prescribed vision therapy/orthoptic treatment regimens. The results were shown only the Office Based Vergence and Accommodation Therapy (OBVAT) group continued to show significant improvements in PFV at weeks 8 and 12.

The rate of improvement is more rapid for clinical signs (NPC and PFV) than for symptoms in children undergoing treatment for CI. OBVAT results in a more rapid improvement in symptoms, NPC and PFV, and a greater percentage of patients reaching pre-determined criteria of success when compared with (Home Based Pencil Push-Ups) HBPP, Home Based Computerized Vergence and accommodation Therapy (HBCVAT+), or Office Based OBPT.

The reason why Scheiman M et al.(2011) to review was that although various treatments were prescribed for patients with convergence insufficiency there was a lack of consensus regarding the most effective treatment. Significant differences existed in the time commitment or compliance of the therapy or treatment for the patient, number of office visits, cost, and complexity of the treatment. A systematic review of clinical trials aimed at summarizing the available evidence on the effectiveness of interventions for patients with convergence insufficiency and would help clinicians select the most appropriate treatments for patients with CI condition.

A total of 475 (half children, half adult) participants in Scheiman M et al. (2011) study gave evidence suggested that Base-in prism reading glasses was no more effective than placebo reading glasses in improving clinical signs or symptoms in children; Second, outpatient vision therapy/orthoptics is more effective than home-based convergence exercises or home-based computer vision therapy/orthoptics in improving clinical signs and symptoms in children; and Third, The effectiveness of various non-surgical interventions in adult population is less consistent. Again, current research pointed that office- based vision therapy/orthoptics was more effective than home-based convergence exercises or home-based computer vision therapy/orthoptics for children.

Shin HS et al. (2011) Symptom scores CISS and clinical signs measures showed significant differences after completion of 12 weeks of treatment. It showed that clinic-based vision therapy was effective for convergence insufficiency and accommodative insufficiency.

One year follow-up examination revealed that the long-term stability of those improved symptoms and clinical signs measures after clinic-based vision therapy.

Alvarez TL et al. (2014) investigated convergence responses and functional activity of the vergence neural substrates before and after repetitive vergence training in symptomatic

CI patients compared to binocular vision normal control subjects.

This fMRI research laid a critical step and foundation in understanding the neural basis of how vergence training leads to a sustained reduction of visual symptoms in patients with CI. As a result, new vergence training protocols may be invented to further improve visual symptoms and clinical signs measures of CI and other vision dysfunctions.

Sreenivasan V. et al. (2014) shown that the reduced magnitude of vergence adaptation found in CI patients resulting in higher levels of Convergence accommodation (CA). Later, Sreenivasan V. et al. (2015) revealed that the reduced vergence adaptation and excessive CA found in CI were normalized through vision therapy, explaining the amelioration of visual symptoms in patients with CI.

Singh NK. et al. (2017) pointed out that Not only the clinical signs measures had clinically significantly changed, but also Stimulus and response AC/A ratio increased following vision therapy, representing the plasticity of the AC/A ratio could be attained in CI patients after vision therapy.

Jang JU. et al. (2017) in Korea's children school, Among convergence insufficiency symptoms, the following improved in particular 3 clinical signs: near point of convergence, exophoria, and near positive fusional vergence. These findings suggested that vision therapy was very effective to ameliorate visual symptoms in convergence insufficiency.

7. Neural basis of vision therapy in Convergence insufficiency

As we suspected the etiology of CI in the disturbance of brain functions involved, there has been applaudable and exciting evidence in vision therapy. Alvarez (2010) was the pioneer to start implementing clinical and functional magnetic resonance imaging measures in adult with convergence insufficiency before and after vision therapy. Firstly, he concluded that convergence peak velocity was significantly slower in CI subjects compared with controls, which may result in asthenopic complaints reported by the CI subjects.

Secondly, vision therapy was associated with and may have evoked clinical and cortical activity changes reflected in fMRI measures after four to one year of vision therapy. The enhanced blood oxygen level and cortical activities in the dorsolateral prefrontal cortex, a portion of the frontal lobe, part of the parietal lobe, the cerebellum, and the brain stem by the effect of vision therapy were documented.

The study pointed out the underlying physiological changes that may correspond with the improvements in clinical signs and CI symptoms after vision therapy. In other words, it suggested that vision therapy may facilitate cortical adaptation and increased activity in the neural networks.

Alvarez TL. (2014) demonstrated how the cortical activities was increased after the performance of repetitive vergence training in the fMRI study of the effect of vision therapy in

neural system. It developed a new scientific experimental study in neural-based vision therapy, shown the neurophysiological effects of vision therapy in patients with CI, which may lead to the sustained reduction in visual symptoms of CI.

Alvarez TL. (2015) further pointed out that the study had clinical translational impact in understanding the mechanism by which vergence therapy changed the vergence system leading to a sustained reduction in visual symptoms.

Further study on neurophysiological effect of vision therapy in CI had been done. Talasan (2016) indicated that the accuracy and temporal properties of vergence fast fusional phasic system and slow fusional tonic system from patients with CI could be led to sustained improvement in visual symptoms after vergence therapy. There were two theories to be tested. The first theory was CI patients had a reduced ability to adapt to near space when they were initially looking in the distance compared to binocularly normal controls. The second theory was CI patients had inadequate disparity vergence to control the phoria compared to binocularly normal controls, which forced them to use excessive neuromuscular innervations to control the deviation and remove diplopia.

Convergence insufficiency is a commonly seen disorder of the vergence system. Its clinical characteristics and symptoms have been well described by Duane and von Graefe. Laboratory studies have clarified the vergence pathway, which includes a bi-phasic response.

Talasan H. et al (2016) explained the complexity of the disparity vergence system, which included both a fast fusional phasic system (FFPS) and a slow fusional tonic system (SFTS). When a vergence disparity stimulus was presented, the SFTS adjusted to the new visual stimulus via adaptation. The importance of improved vergence adaptation appears to arise from a reduction in excessive convergence accommodation in patients with CI (Sreenivasan & Bobier, 2014) in whom phoria adaptation is improved after vision therapy (Sreenivasan & Bobier, 2015)

7.1 Associated with reading and learning

There were some studies ongoing to investigate the relationship between the near point of convergence and oculomotor movement in reading skills and learning.

Ophthalmologists also interested in this area. Morad Y et al (2002) concluded that Convergence amplitude measured while accommodation is controlled was correlated with the DEM score. Cohen Y et al.(2010) found that asthenopic symptoms score was correlated with the convergence amplitude.

Researchers started to find the relationship between CI and reading skill and learning. Dusek_WA et al. (2011) study found that reading difficulties with no apparent intellectual or psychological foundation may be due to a binocular vision anomaly such as convergence insufficiency.

Borsting E, Mitchell GL, Kulp MT, CITT study group et al. (2012) introduced Academic Behavior Survey (ABS) scores to assess the effect of the treatment of symptomatic convergence insufficiency (CI). They concluded that a successful or improved outcome after CI treatment was associated with a reduction in the frequency of adverse academic behaviors and parental concern associated with reading and school work as reported by parents.

CITT - ART group started to run another large-scale randomized controlled multicentre and double masked treatment trial research in 2015.

Hussaindeen JR. et al. (2017) reported that the school children with learning disability had high prevalence of binocular dysfunctions, including Convergence insufficiency, which could be treated by vision therapy effectively.

7.2 Concussion related CI

Master CL et al (2016) reported that overall, 69% had one or more of the following vision diagnoses: accommodative disorders (51%), convergence insufficiency (49%), and saccadic dysfunction (29%) in patients aged 11 to 17. Overall, 46% of patients had more than one vision diagnosis. A high prevalence of vision diagnosis in adolescent subjects with concussion manifested more than one Vision disorder, including accommodative, binocular convergence, and saccadic eye movement.

Gallaway et al. (2016) conducted a research on Vision therapy on Concussion related visual disorder. Binocular vision disorder was diagnosed in 62%, accommodative disorder was found in 54% and saccadic function in 21.6% of patients. Vision therapy was recommended for 175 of the 218 patients. In patients treated with vision therapy for convergence insufficiency (CI), 85% had a successful outcome, and 15% improved. Among those with accommodative insufficiency (AI), 33% were successful, and 67% improved, and for patients with saccadic dysfunction, 83% were successful and 5% improved.

Gallaway et al (2017) found that post-concussion vision problems were prevalent. CI and AI were the most commonly diagnosed in clinical signs. After completion of vision therapy, the vast majority of cases had a successful or improved outcome in the treatment. Evaluation of patients with a history of concussion should include testing of vergence, accommodative, and eye movement function.

Conrad JS. et al (2017) concluded that there was significant improvement in the binocular dysfunctions after post brain injuries. Almost 70% of the subjects had different extent of improvement in clinical measures.

Swanson MW. et al (2017) indicated that there were a association between academic Difficulty and Vision Symptoms in Children with Concussion. Vision problems were commonly reported in children with concussions. Especially those with symptoms more than a month after concussion and were independently associated with those reporting academic difficulty. They suggested that a comprehensive vision assessment should be considered in children reporting academic difficulty and in the development of return-to-learn protocols.

7.3 ADHD related CI

There were many researchers studied the association between ADHD in CI. Borsting and the CITT group (2005) conducted a preliminary study suggest that school-aged children with symptomatic accommodative dysfunction or CI have a higher frequency of behaviors related to school performance and attention.

Rouse et al (2009) suggested that children with parent-report of ADHD or related learning problems could benefit from comprehensive vision evaluation to assess for the presence of CI.

Lee et al (2014) concluded that Convergence insufficiency symptoms are closely related to symptoms screened for ADHD, and also agreed that vision therapy to improve vergence movements was an effective method of relieving the visual symptoms in ADHD.

Puig et al. (2015), psychologists in Spain, also found the relationship of vergence eye movement and attention in ADHD.

Borsting and Rouse (2016) reported that vision therapy of CI children had significant improvement in the test of ADHD.

7.4 Others related Convergence insufficiency.

Convergence insufficiency also found in Pathological, Neurological (Parkinson disease), medicine (Antidepressants), functional, systemic, learning disability (dyslexic, ADHD, ADD), Traumatic (concussion, TBI), Aging.

8. Different point of views on convergence insufficiency studies

Kushner BJ (2005) criticized Scheiman and colleagues (2005c) survey and Randomized clinical trial pilot study that 23% of other ophthalmic clinicians was a low response rate to the survey. It misled him respect to their community. He seemed to support about the use pencil push-ups in their community that the method of performing exercise and the intensity of the treatment was not addressed. He quoted 5% pediatric ophthalmic clinician were underrepresented to those orthoptists who treated the majority of the patients with CI.

He argued those eye training technicians were then surveyed and replied that "Typically, the treatments of CI involve having the patients to converge on a target as it moved to closer to the eye" aid to improve the fusional convergence and in some cases accommodative convergence. "This type of exercise is called pencil push-up. The amount of convergence needed in the exercise is always equal to just that amount necessary to maintain bifoveal fixation at the given distance. This exercise can be made more challenging

by having the patient perform it while looking through base-out prisms."

First of all, Jethani J (2005) cited Kushner's queries on the treatment trial in office- based vision therapy was more intensive the home-based push-up treatment. Besides, pencil push-ups were not instructed to do alone commonly. Jethani congratulated Scheiman M and his colleagues in the CITT survey which was the first large-scale, randomized, double - blinded, controlled clinical treatment trial. Jethani further commented Scheiman and colleagues that the treatment protocol had done was only subjective and they should undertake the study and prepare the ground for a more vigorous randomized clinical trial that would address the above issues.

The reply from Scheiman and colleagues clarified the inaccurate calculations of the time for each treatment. The total time for home based pencil push-ups was 15 hours; whereas the office based vision therapy was 27 hours.

David K. Wallace (2008) also commented on another randomized clinical treatment trial, which was conducted by Scheiman and colleagues in 2008, that " not all patients with convergence insufficiency are symptomatic, and for those patients, treatment is generally unnecessary. Conversely, many patients with asthenopic symptoms have normal convergence".

Mc Gregor. (2014) pointed out that convergence therapy was not effective in treating learning disabilities, but could sometimes relieve symptoms that might be a barrier to reading. He seemed did not fully understand visual therapy composed of not only convergence training and divergence training, but also accommodative training, ocular motility, visual processing, visual perception, and visual integration.

Clark et al (2017) compared Convergence Insufficiency Symptom Survey scores for required reading for school versus scores for leisure reading. They criticized Convergence Insufficiency Symptom Survey scores varied greatly depending on the type of near activity being surveyed and thus did not accurately isolate and reflected near visual ability.

9. Conclusion

As far as convergence insufficiency is concerned, it can be associated and diagnosed in so many problems which are related with it. Before diagnosing and treating the convergence insufficiency of our patients, it is crucial and vital important in filtering and excluding any hidden or primary organic eye diseases.

The establishment of the CI definition and the prevalence of CI were the important steps in putting vision therapy through scientific research and clinical proven evidence in treating CI.

With the completion of several randomized clinical trials in the past decade, scientific evidence statistically proved that office based vision therapy was the most effective in the treatment of patients with CI. Base in reading glasses or

pencil push-ups had been indicated to be statistically insignificant.

The introduction of a new objective measure of disparity vergence as the primary outcome in treatment of Concussion-related CI will be the milestone for further research in the effect of vision therapy for other strabismic and non-strabismic binocular dysfunctions.

Scientific evidence exists for the efficacy of vision therapy for convergence insufficiency. It would be a good milestone to conduct other scientific researches and studies and provide a solid evidence for treatment of the other non-strabismic binocular anomalies and accommodative disorders.

Binocular anomalies, especially convergence insufficiency, could potentially be found in learning disability and developmental delay population, added hindrance to the reading difficulty in those special need populations. CI affects a very wide range of visual functions, visual information processing, visual perception and visual cognition development, and establishment of visual integration. Vision therapy can really change people's life.

References

[1] Adler P. (2002). Efficacy of treatment for convergence insufficiency using vision therapy. *Ophthalmic Physiol Opt.*22(6):565-71.

[2] Alvarez TL. (2015). A pilot study of disparity vergence and near dissociated phoria in convergence insufficiency patients before vs. after vergence therapy. *Front Hum Neurosci.* 2015 Jul 27;9:419.

[3] Alvarez TL, Jaswal R, Gohel S, Biswal BB. (2014). Functional activity within the frontal eye fields, posterior parietal cortex, and cerebellar vermis significantly correlates to symmetrical vergence peak velocity: an ROI-based, fMRI study of vergence training. *Front Integr Neurosci.* 17;8:50.

[4] Alvarez TL. et al. (2010). Vision therapy in adults with convergence insufficiency: clinical and functional magnetic resonance imaging measures. *Optom Vis Sci.* 87(12): E 985-1002.

[5] Bade A. et al. (2013). Relationship between clinical signs and symptoms of convergence insufficiency. *Optom Vis Sci.* 90(9):988-95.

[6] Barnhardt C. et al. (2012). Symptoms in Children with Convergence Insufficiency: Before and After Treatment. *Optom Vis Sci.*89(10): 1512–1520.

[7] Borsting E. et al. (2012). Improvement in academic behaviors after successful treatment of convergence insufficiency. *Optom Vis Sci.* 89:12–18.

[8] Borsting E, Rouse M, Chu R. (2005). Measuring ADHD behaviors in children with symptomatic accommodative dysfunction or convergence insufficiency: a preliminary study. *Optometry.* 76:588–592.

[9] Borsting E. (2003a). Association of symptoms and convergence and accommodative insufficiency in school-age children. *Optometry.*74(1):25-34.

[10] Borsting E, Rouse MW, Deland PN. (1999). Prospective comparison of convergence insufficiency and normal binocular children on CIRS symptom surveys.

Convergence Insufficiency and Reading Study (CIRS) group. *Optom Vis Sci.* 76(4):221–228.

[11] Borsting E. et al. (2016). Behavioral and emotional problems associated with convergence insufficiency in children: An open trial. *J Atten Disord.* 20(10):836-44.

[12] Borsting EJ. (2003b). Validity and reliability of the revised convergence insufficiency symptom survey in children aged 9 to 18 years. *Optom Vis Sci.* ; 80(12):832-8.

[13] Cacho-Martínez P, García-Muñoz Á, Ruiz-Cantero MT. (2014). Is there any evidence for the validity of diagnostic criteria used for accommodative and non-strabismic binocular dysfunctions? *J Optom.* 7(1):2-21.

[14] Clark TY, Clark RA. (2017). Convergence Insufficiency Symptom Survey scores for required reading versus leisure reading in school-age children. *J AAPOS.* pii:S1091-8531(17)30235-5.

[15] Cohen Y. et al. (2010). Correlation between asthenopic symptoms and different measurements of convergence and reading comprehension and saccadic fixation eye movements. *Optometry.* 81:28–34.

[16] Conrad JS1, Mitchell GL, Kulp MT. (2017). Vision Therapy for Binocular Dysfunction Post Brain Injury. *Optom Vis Sci.* 94(1):101-107.

[17] Cooper J, Jamal N. (2012). Convergence insufficiency-a major review. *Optometry.* 30;83(4):137-58.

[18] Wallace DK. (2008). Treatment Options for Symptomatic Convergence Insufficiency. *Arch Ophthalmol.* 126(10):1455-1456.

[19] Dusek WA, Pierscionek BK, McClelland JF. (2011). An evaluation of clinical treatment of convergence insufficiency for children with reading difficulties. *BMC Ophthalmol.* 11: 21.

[20] Gallaway M, Scheiman M, Mitchell GL. (2017). Vision Therapy for Post-Concussion Vision Disorders. *Optom Vis Sci.* 94(1):68-73.

[21] Jang JU, and Inn-Jee Park. (2015). Prevalence of general binocular dysfunctions among rural schoolchildren in South Korea. *Taiwan J Ophthalmol.* 5(4): 177–181.

[22] Jang JU, Jang JY, Tai-Hyung K, Moon HW. (2017). Effectiveness of Vision Therapy in School Children with Symptomatic Convergence Insufficiency. *J Ophthalmic Vis Res.* 12(2):187-192.

[23] Jethani J. (2005). Convergence Insufficiency: Randomized Clinical Trial. *Arch Ophthalmol.* 123(12):1760-1761.

[24] Kushner BJ. (2005). The treatment of convergence insufficiency. *Arch Ophthalmol.* 123(1):100-1.

[25] Lee SH, Moon BY, Cho HG. (2014). Improvement of vergence movements by vision therapy decreases K-ARS scores of symptomatic ADHD children. *J Phys Ther Sci.* 26:223–227.

[26] Morad Y. et al. (2002). Correlation between reading skills and different measurements of convergence amplitude. *Curr Eye Res.* 25(2):117-21.

[27] Master CL. et al. (2016). Vision Diagnoses Are Common After Concussion in Adolescents. *Clin Pediatr (Phila).* 55(3):260-7.

[28] Rouse M. et al. (2009). Academic behaviors in children with convergence insufficiency with and without parent-reported ADHD. *Optom Vis Sci.* 86:1169–1177.

[29] Rouse MW. et al. (1999). Frequency of convergence insufficiency among fifth and sixth graders. The Convergence Insufficiency and Reading Study (CIRS) group. *Optom Vis Sci.* 76(9): 643-9.

[30] Rouse, M.W. et al. (2004). Validity and reliability of the revised convergence insufficiency symptom survey in adults. *Ophthalmic Physiol Opt.* 24(5):384-90.

[31] Rouse, M.W., Hyman, L., Hussein, M., Solan, H. (1998). Frequency of convergence insufficiency in optometry clinic settings. Convergence Insufficiency and Reading Study (CIRS) Group. *Optom Vis Sci.* 75(2):88-96.

[32] Rouse, M.W., The Convergence Insufficiency Treatment Trial (CITT) Investigator Group. et al. (2009).Validity of the convergence insufficiency symptom survey: A confirmatory study. *Optom Vis Sci.,*86:357–63.

[33] Scheiman, M., Wick, B. (2002). *Clinical management of binocular vision*. LWW.p4-5.

[34] Scheiman, M., The Convergence Insufficiency Treatment Trial (CITT) Study Group. (2005b). Randomised clinical trial of the effectiveness of base-in prism reading glasses versus placebo reading glasses for symptomatic convergence insufficiency in children. *Br J Ophthalmol.* 89(10): 1318–1323.

[35] Scheiman, M., Gwiazda, J., Li, T. (2011). Non-surgical interventions for convergence insufficiency. *Cochrane Database of Systematic Reviews.* (3):CD006768.

[36] Scheiman, M., The Convergence Insufficiency Treatment Trial Study Group. et al. (2010). Vision Therapy/Orthoptics for Symptomatic Convergence Insufficiency in Children: Treatment Kinetics. *Optom Vis Sci.* 87(8): 593–603.

[37] Scheiman, M. et al. (2005c). A randomized clinical trial of vision therapy/orthoptics versus pencil pushups for the treatment of convergence insufficiency in young adults. *Optom Vis Sci.* 82:583–595.

[38] Scheiman, M. et al. (2005a). A randomized clinical trial of treatments for convergence insufficiency in children. *Arch Ophthalmol.* 123(1):14–24.

[39] Scheiman M. et al. (2009). Treatment of convergence insufficiency in childhood: a current perspective. *Optom Vis Sci.* 86(5):420-8.

[40] Scheiman, M., Talasan, H., Mitchell, G. L., Alvarez, T. L. (2017). Objective Assessment of Vergence after Treatment of Concussion-Related CI: A Pilot Study. *Optom Vis Sci.* 94(1):74-88.

[41] Singh, N.K., Revathy, M., and Hussain, J. R. (2017). Changes in stimulus and response AC/A ratio with vision therapy in Convergence Insufficiency. *J Optom.* 10(3): 169–175.

[42] Sreenivasan, V., Bobier, W. R. (2014). Reduced vergence adaptation is associated with a prolonged output of convergence accommodation in convergence insufficiency. *Vision Res.* 100:99-104.

[43] Swanson, M.W. et al. (2017). Academic Difficulty and Vision Symptoms in Children with Concussion. *Optom Vis Sci.* 94(1):60-67.

[44] Talasan, H., Scheiman, M., Li, X., Alvarez, T.L. (2016). Disparity vergence responses before versus after repetitive vergence therapy in binocularly normal controls. *J Vis.* 16(1):7.

[45] The Convergence Insufficiency Treatment Trial (CITT) Study Group. (2008a).The convergence insufficiency treatment trial: design, methods, and baseline data. *Ophthalmic Epidemiol.* ;15:24–36.
[46] The Convergence Insufficiency Treatment Trial (CITT) Study Group. (2008b). Randomized clinical trial of treatments for symptomatic convergence insufficiency in children. *Arch Ophthalmol.*126:1336–49.