The effect of convergence insufficiency treatment on reading performance in school age children – A meta-analysis

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Abstract

Introduction/purpose: Convergence insufficiency (CI) is a binocular vision disorder characterised by difficulty maintaining convergence and fixation at near. Depending on the severity of the CI, patients can present with a variety of symptoms during near vision tasks.
Some studies indicate an increased incidence of CI in children with reading difficulties. Although a lot of research has been done on the effects of CI-treatments on eye-related symptoms, not much is known about its effect on performance related symptoms such as reading difficulties. The purpose of this meta-analysis is to determine if CI-treatments have a positive effect on reading performance.
Methods: A search string was created to gather all relevant clinical trials on the National Centre for Biotechnology Information (NCBI) and Cochrane libraries. Only clinical trials were included that provided pre- and post treatment data on the effect of CI-treatment on reading performance in school aged children (5-18y). A total of three relevant clinical trials were found that provided pre-and post-treatment data.
Results: A total of 352 subjects in CI-treatment groups across three clinical trials and 104 subjects in a placebo group provided pre-and post CI-treatment data on the improvements of reading performance in school aged children. The cumulative within-group treatment effect size (0.21(SD 0.03) [95%CI: 0.15, 0.27]) and the cumulative within-group placebo effect size (0.22(SD 0.05) [95%CI: 0.13, 0.32]) for the improvement of reading performance after CI-treatment in school aged children with CI was calculated.
Conclusion: CI-treatment has little to no true effect size on reading performance. Though CI-treatments will cause an increase in reading performance, this is likely caused by improvements in attention, motivation, or other psychological factors (placebo effect).

Keywords: Convergence-insufficiency; reading and writing skills; visual therapy; binocular vision disorder; CI-treatment

1. Introduction

Convergence insufficiency (CI) is a binocular vision disorder characterised by difficulty maintaining convergence and fixation at near, resulting in an exophoria at close distance. The cause of CI is not known, though it can be classified based on its coincidence with certain pathologies (Ostrow & Kirkeby, 2022). When CI is present in a healthy individual it is classified as an isolated CI (not related to trauma or neurological disease). If CI appears after trauma or neurological disease it is classified as an acquired CI. For the purpose of this study all further mentioned CI will be of the isolated type.

In most literature, CI is described and diagnosed as having a decreased near point of convergence (NPC) (5/6cm break for non-symptomatic CI and 7.5/10cm break for symptomatic CI), an exodeviation 6 to 8 prism dioptres (Δ) greater at near than at distance and reduced positive fusional reserves (PFV) at distance (failing Sheard's criterion) (Trieu & Lavrich , 2018) (Menjivar et al., 2018) (Rutstein & Daum, 1998). Though CI is recognised by the World Health Organisation (WHO) as a disease (ICD-10 : H51.11) there is no consensus on the diagnostic criteria.

The diagnosis of CI is therefore often supplemented by the analysis of symptoms using the Convergence Insufficiency Symptoms Survey (CISS). The CISS is a questionnaire that scores the prevalence and severity of eye-related and performance related symptoms. However, a recent study by Clark & Clark (2017) has

indicated that the subjective nature of the CISS, and the child's interpretation of the questions, can influence the score. Academic reading tasks scored higher (worse) in comparison to leisure reading tasks even if near visual skills were identical.

Depending on the severity of the CI patients can present with asthenopia, blurry vision, headaches, diplopia, dizziness, motion sickness and nausea (Trieu & Lavrich , 2018). Performance related symptoms (e.g., difficulties reading, concentrating or studying) can also be present besides the aforementioned eye-related symptoms. According to a study by Barnhardt et al. (2012), performance related symptoms were reported more frequently by patients with CI, regardless of ethnicity, sex, age, or parent-reported attention deficit hyperactivity disorder (ADHD).

CI has a prevalence ranging from 2% to 13%, with 5% being the prevalence most cited in literature (Goering et al., 2021). This range increases to 14%-38% in children with learning disorders (Hussaindeen et al., 2017). Multiple studies show an increased incidence of CI in children with reading difficulties. However, these studies fail to determine a causal relationship between the two conditions (Phillips, 2017). Because of the increased near vision demanding tasks in school aged children the treatment of CI has become a topic generating a significant amount of coverage and discussions. It is, currently, the only form of visual therapy that is supported by scientific evidence.

Office-based vergence/accommodation therapy (OBVAT) is an effective form of visual therapy for CI according to a study by the CITT-ART investigator group (2019). Other forms of CI-treatment, such as Base-In (BI) prism glasses and outpatient vision therapy were less effective and showed, in some instances, no greater treatment effect than the placebo treatments (Scheiman et al., 2011). Most studies investigating the effects of CI treatment use the CI-diagnostic criteria (NPC, exophoria and PFV) or symptoms as dependent variables. However, not much is known about the performance related improvements of CI-treatment.

It is not clear if there is a causal relationship between reading difficulties and CI. Reading skills are one of the important pillars of academic performance and it would seem logical to assume that a binocular vision disorder that causes a wide array of symptoms during near visual task might negatively influence reading performance. However, it is widely agreed upon in the paediatric community that learning disabilities are not caused by binocular disorders and that vision therapy has no impact in treating learning disabilities (McGregor, 2014).

Though it is known that CI-treatments can improve symptoms, not much is known about its effect on reading performance. The purpose of this meta-analysis is to determine if the treatment of CI has a positive effect on reading performance. This information can help clinicians and visual therapists to determine the prognosis of CI-treatment and to recommend the appropriate treatment options.

2. Methods

Eligibility criteria

Only randomized control trials (RCT's) and clinical trials (CT's) were included in this review. Articles had to provide detailed information about study-design, population, intervention, and outcome. Trials had to directly study the effects of convergence insufficiency (CI) treatments on reading performance in school age children (5-18y). Study outcome must be reading performance, measured in either speed, fluency, comprehension or error rate.

Pre- and post-intervention reading performance must be documented. Intervention type must be reported and can be either non-surgical (visual therapy, BI prism) or surgical (extra-ocular muscle resection, botulinum toxin injection). The effectiveness of the treatment should preferably be assessed by comparing NPC, PFV and the difference in near and far angle of deviation before and after treatment.

Population size must be over one hundred, although smaller sample sizes were also considered for eligibility. Ethnicity, race, gender, language or nationality were not considered in the inclusion criteria as there is no evidence to indicate that these factors play a significant role in CI, or the effectiveness of CI treatments. Articles will not be filtered on publication date as the treatment methods for CI and the testing methods for reading performance are not fundamentally influenced by medical or technological advances.

Search strategy

The search was performed using the PubMed and Cochrane libraries during the month of September 2021. These libraries are a collection of various databases such as, but not limited to, PubMed, PubMed Central, Embase, CENTRAL. A search string was designed that would create a large number of relevant search terms combinations: (((“reading” OR ("reading" AND ("aptitude" OR "ability" OR "speed" OR "fluency" OR "performance"))) OR "academic performance") AND ("convergence insufficiency" OR ("convergence insufficiency" AND ("therapy" OR "treatment")))). The use of Medical Subject Headings (MeSH terms) was avoided as both indexed and non-indexed articles would be reviewed for inclusion.

Data collection and analysis

Where possible, the available filter was used to only include RCT's and CT's. Articles were screened for relevance by reading the title and/or abstract. The full text of any relevant study was then examined to determine if it met the inclusion criteria. If the article met the inclusion criteria it was added to the final selection. The screening and selection process was performed by the author of this review.

To interpret the different findings of the selected articles, all available data about pre- and post-CI treatment was analysed and effect size, by means of Hedge's g, was calculated. After which a cumulative weighted treatment effect size and a cumulative weighted placebo effect size was calculated.

Effect size (Hedge's g) and cumulative weighted effect size was calculated with the Comprehensive Meta Analysis V3 software.

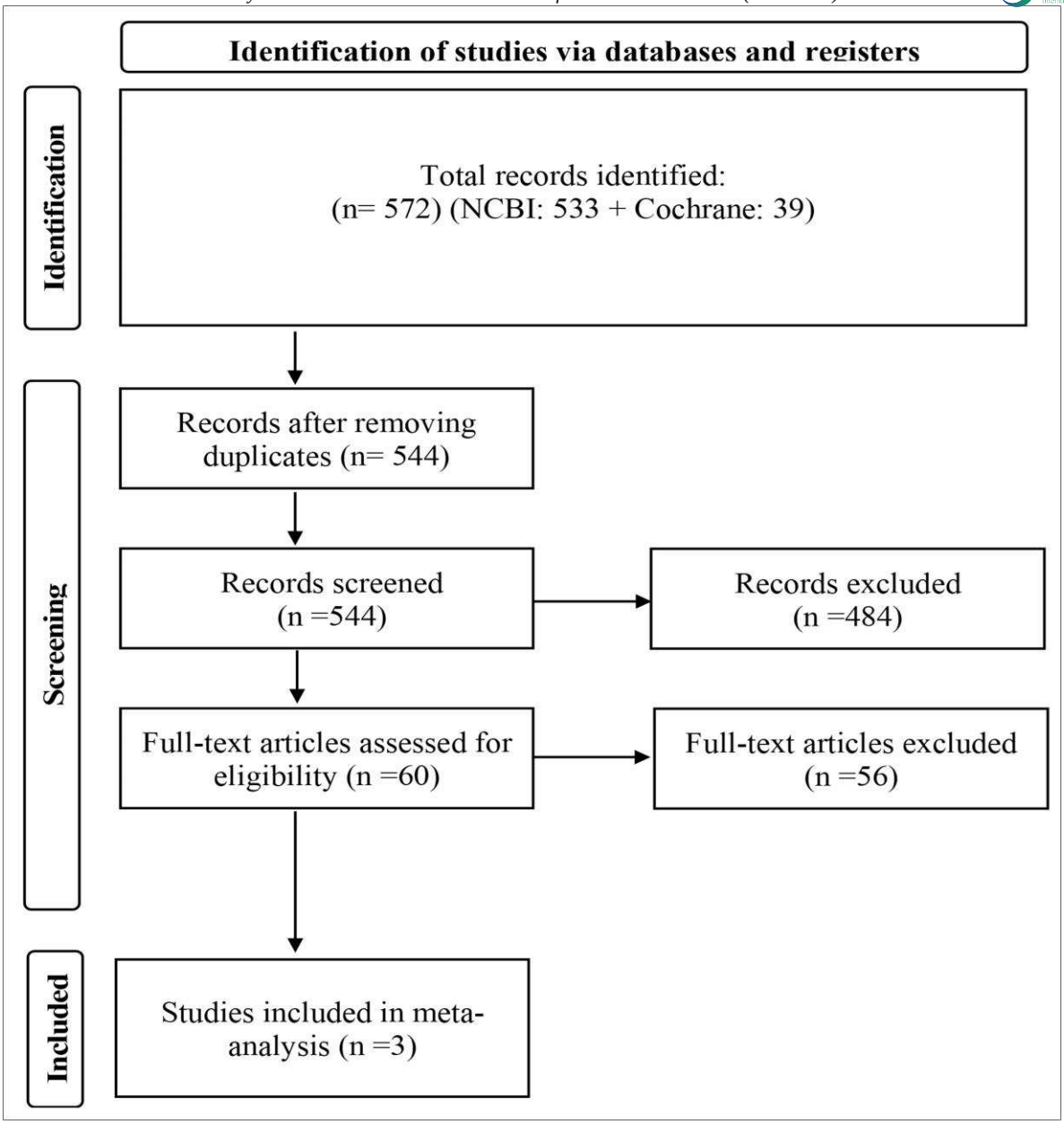

Fig. 1. PRISMA flow-chart of the search strategy that was implemented in this meta-analysis.

3. Results

After screening 572 articles, only four were relevant to the research question. The study by Stavis et al. (2002) failed to provide any pre- and post-treatment data and could therefore not be included in the meta-analysis. Though Stavis et al. (2002) concluded that, based on a treatment group of only 33 subjects with CI, BI-prism glasses improved reading performance. However, this study must be viewed sceptically as it has a small sample size, has no control or placebo group, selected subjects on their baseline reading improvements with BI-prism glasses and failed to provide any pre- and post-treatment data.

The remaining three studies did provide their study set-up and the pre- and post-treatment data. To determine the validity of their results all three articles were analysed qualitatively by the author of this meta-analysis. A small description of each included study that was used in the meta-analysis is provided in the following chapters (Clinical Trial 1 to 3).

3.1 Clinical trial 1

Dusek et al. (2011) studied the effect of 2 different CI treatments on a population of 134 subjects (7-14 years of age) with CI and reading difficulties. All subjects were screened by an educational psychologist and had an IQ of over 70. Subjects with ocular pathologies were excluded. The diagnosis of CI was confirmed if all of the following first three criteria, and at least one of the additional signs (point 4 and/or 5), were met: (i) a NPC larger than six cm; (ii) an exophoria at least six prism dioptres larger at near than at distance; (iii) an accommodative convergence to accommodation ratio (AC/A) lower than 2:1; (iv) a binocular accommodative facility (BAF) of less than 6cpm (+2.00/-2.00 flipper) and a monocular accommodative facility (MAF) more than 10cpm; (v) a vergence facility of less than 6cpm (base-out (BO) prism).

The two different CI-treatments consisted of a computerised home visual therapy system (HTS) and glasses with eight base-in prism dioptres (D). Subjects, and their parents, were allowed to choose either one of the two treatment options. After treatment selection both the HTS-group and the prism-group contained 51 subjects. Subjects who refused both treatments served as a control group (n=32). After four weeks of either prism or HTS therapy, all tests performed at baseline were repeated.

Reading performance was measured by an Austrian test, called the Salzburg Reading Test (SRT). The mean total pre- and post-treatment reading times and mean reading error scores of the control-group, HTS-group and prism-group are listed in Appendix A (Table A1).

This study by Dusek et al. (2011) concluded that base-in prism glasses are an effective treatment option for children with CI and reading difficulties. However, because of the small population size and the lack of a placebo group we cannot assume the reported treatment effect represent the true treatment effects size.

3.2 Clinical trial 2

The pilot study by Scheiman et al. (2018), which is the preliminary study for a larger clinical trial by the Convergence Insufficiency Treatment Trial (CITT) investigator group, studied the effect of CI-treatment on reading performance in children with symptomatic CI.

Office-based vergence/accommodative therapy (OBVAT) with home reinforcement was administered to 44 subjects (age 9-17) with symptomatic convergence insufficiency. Participants were selected based on specific inclusion/exclusion criteria (Appendix B). Baseline reading tests were administered withing two weeks of inclusion. Significant refractive errors were corrected based on a cycloplegic refraction. Four reading tests were used to assess reading performance: the Wechsler Individual Achievement Test, 2nd Edition (WIAT-II),

the Gray Oral Reading Test (GORT-4), the Test of Word Reading Efficiency (TOWRE), and the Test of Silent Word Reading Fluency (TOSWRF).

OBVAT was prescribed for 16 weeks with 60 minutes in-office therapy, supplemented by 15 minutes of daily home exercises. After the 16 weeks of OBVAT participants were administered all initial baseline tests and prescribed home maintenance therapy for 8 weeks. After 24 weeks all base line tests and reading tests were repeated. The mean reading test score change from baseline can be found in appendix A (Table A2).

Scheiman et al. (2018) reported significant improvements in reading comprehension and composite reading scores in the WIAT-II test. These improvements positively correlated with successful CI-treatment. Reading speed as tested by the GORT-4 also showed a significant improvement.

This pilot study served as a preliminary trial to prepare for a large-scale randomised clinical trial. It is limited by a small sample size and the lack of a control group.

3.3 Clinical trial 3

The CITT-ART Investigator Group (2019) launched the first and, up to this point, only clinical double-blind trial testing the effect of CI-treatment on reading performance. The pilot study by Scheiman et al. (2018) indicated a small treatment effect, and the CITT-ART improved upon its study design by implementing a larger sample size and the addition of a placebo control group.

A total of 310 subjects (age 9-14) with symptomatic CI were selected based on specific inclusion/exclusion criteria (appendix C). Subjects were randomly assigned in a 2:1 ratio to the treatment group (206 subjects) and placebo group (104 subjects). Significant refractive errors were corrected based on a cycloplegic refraction. Baseline CI and reading performance testing were performed within 2 weeks of selection. Both participant and examiner were masked to the treatment.

The Wechsler Individual Achievement Test, Third Edition (WIAT-III), Gates-MacGinitie Reading Tests, Fourth Edition (GMRT-4), AIMSweb R-CBM test of oral reading fluency and AIMSweb Maze tests were used to assess reading performance. Treatment consisted of 16 weekly, 60 minute in-office vergence/accommodative therapy (V-A therapy) sessions that were similar in design for both treatment and placebo group. Follow-up visits were performed in 4-week intervals with a final visit after 16 weeks. At the final 16-week visit an examiner repeated the reading tests performed at baseline. The mean change in reading scores from baseline for both treatment and placebo groups are listed in Appendix A (Table A3).

The CITT-ART investigators concluded that 16 weeks of V-A therapy was no more effective than 16 weeks of placebo therapy. The study reports the effect sizes of 16 weeks of V-A therapy compared to the post-treatment placebo group (Appendix A, Table A4).

4. Analysis

Pre- and post- treatment results from the treatment groups of all three included studies were used to calculate the within-group treatment effect sizes (Hedge's g). The results of this analysis are shown in Appendix D (Table D1) and illustrated in a forest plot (Figure 2).

Hedge's g effect sizes can be interpreted using the following rule: small effect size = 0.2, medium effect size = 0.5 and large effect size = 0.8. Following this rule, a small weighted cumulative treatment effect size can be seen (0.21(SD 0.03) [95%CI: 0.15, 0.27]). This effect size provides an estimate of the average expected effect size for reading performance improvements after CI-treatment (BI-prism glasses and visual therapy).

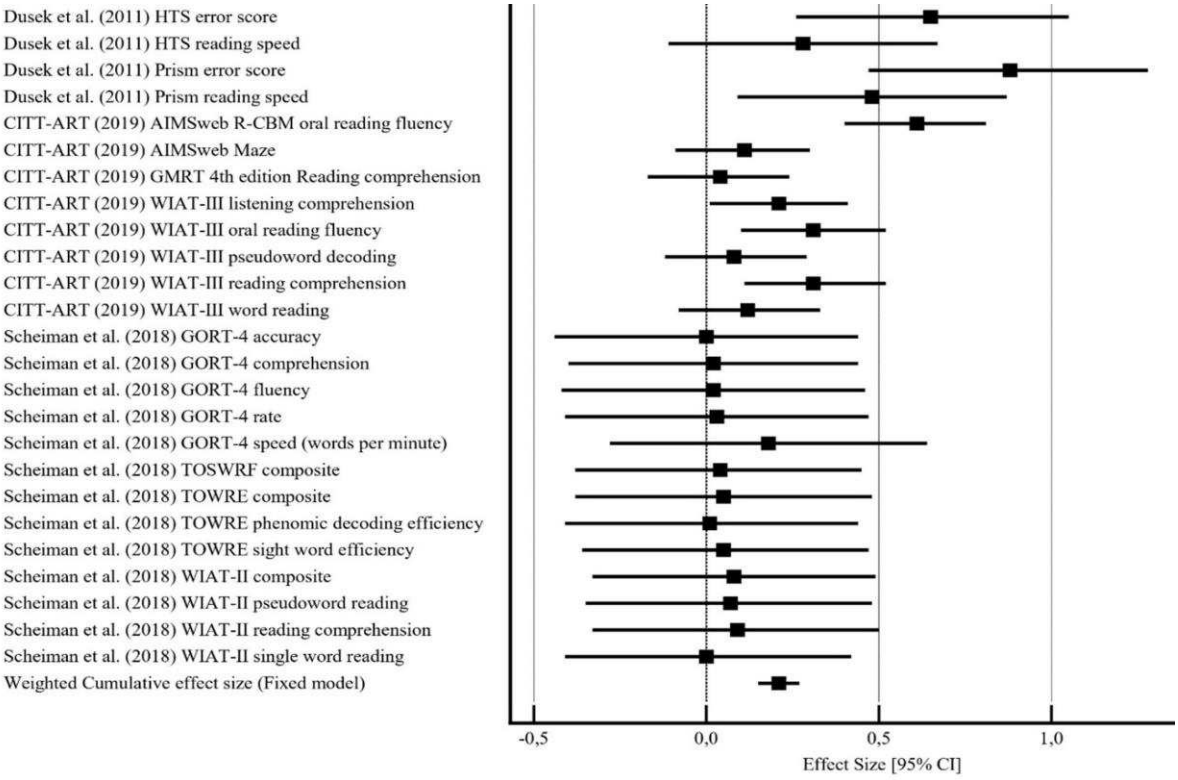

Fig. 2. Forest plot illustrating the treatment effect sizes from table D1.

Using the CITT-ART (2019) placebo group data a weighted cumulative placebo effect size was calculated. This effect size provides an estimate of the average effect induced by the placebo effect. The results of this calculation are shown in Appendix D (Table D2) and illustrated in a forest plot (Figure 3). Analysis of the placebo group revealed a small weighted cumulative placebo effect size (0.22(SD 0.05) [95%CI: 0.13, 0.32]). Indicating that some placebo effect is present when patients receive CI-treatment.

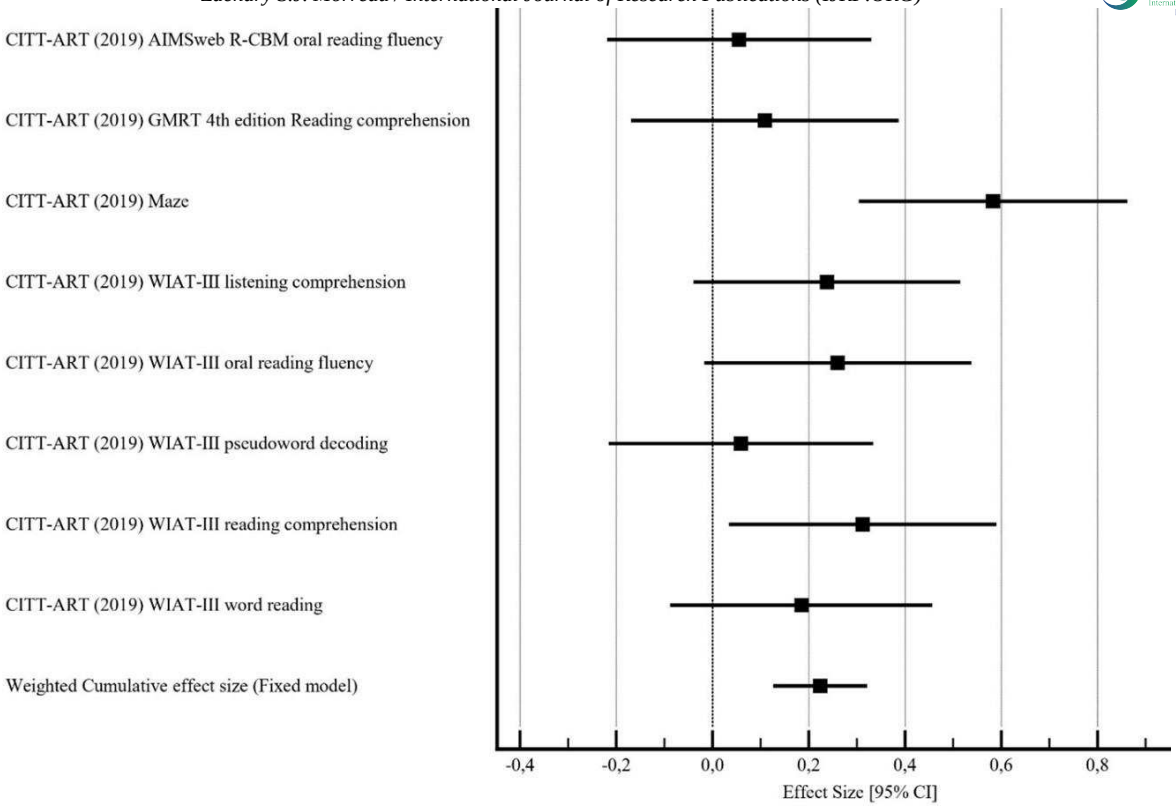

Figure 3. Forest plot illustrating the placebo effect sizes from table D2

To determine if CI-treatment has a true effect, we had to analyse the difference between the treatment effect and the placebo effect. This was done with an independent sample t-test. A mean difference in test scores of -0.01(0.004) [95%CI: -0,0179, -0,002] was calculated between the treatment and placebo group (p 0.0131). This indicates that the placebo treatment was more effective than the actual CI-treatment.

4.1 Publication bias

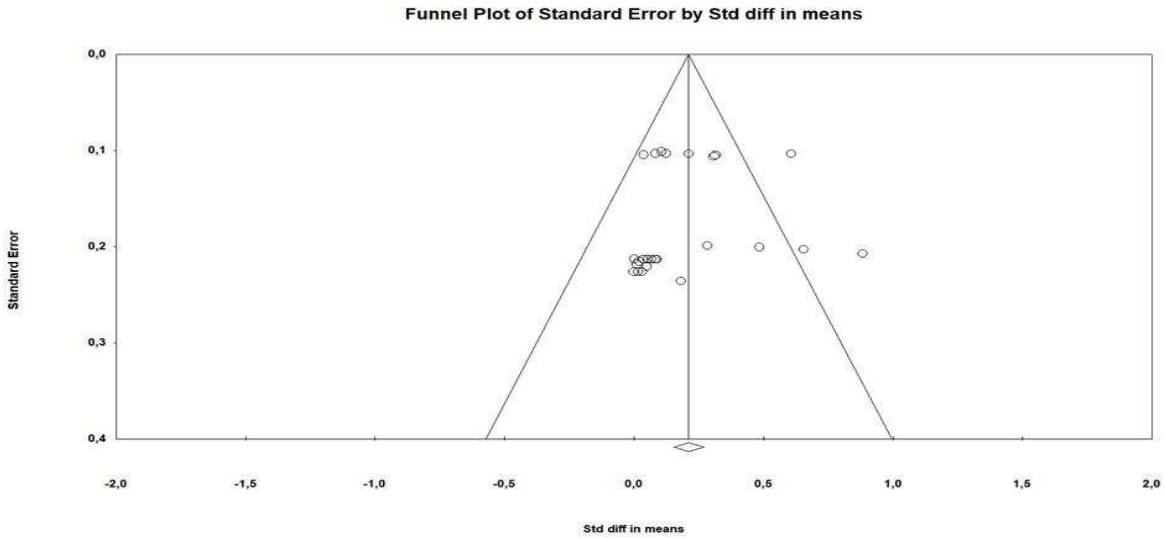

Figure 4. Funnel plot of standard error by Std diff in means

No publication bias was present according to Egger's test (Intercept (B0): -0.48313 [95%CI: -2,17593, 1,20967], 1-tailed p-value: 0.28).

5. Discussion

This meta-analysis is, up to this point, the only review that provides objective quantitative data about CI-treatment and reading performance and includes all available clinical trials that directly test the correlation between reading performance and CI-treatment. In total 352 subjects in CI-treatment groups across three clinical trials and 104 subjects in a placebo group were analysed after which the cumulative treatment and placebo effect sizes for the improvement of reading performance after CI-treatment in school aged children with CI was calculated.

A cumulative effect size (Hedge's g) of 0.21(SD 0.03) [95%CI: 0.15, 0.27] indicates that CI-treatments (V/A therapy, BI-prism glasses) have a small positive effect on reading performance in school aged children with CI. However, this effect can not be attributed to the actual treatment of CI. This becomes evident when the cumulative treatment effect size is compared with the cumulative placebo effect size from the CITT-ART (2019) study (0.22(SD 0.05) [95%CI: 0.13, 0.32]). Subjects in the placebo group showed improvements in reading performance greater to those of the treatment group, with a mean difference in reading score of -0.01(0.004) [95%CI: -0,0179, -0,002] (p 0.0131). CI-treatment seems no more effective in improving reading performance than placebo therapy in school aged children. These results support the findings of the CITT-ART study group.

It remains unclear if there is a causal relation between CI and reading performance. Reading performance is determined by many factors other than visual function. The review on CI and reading difficulties by Philips (2017) commented on the lack of specificity in CI diagnostic tools and criteria, which is one of the main issues and challenges that future researchers will need to face. The use of the CISS questionnaire or other symptom based diagnostic tools should be avoided for diagnosing CI for clinical trial purposes as they are not specific

enough. Moreover, there is no scientific evidence indicating a causal relation between performance-related symptoms and CI, even in children diagnosed with CI.

The American Academy of Paediatrics (Section on Ophthalmology, Council on Children with Disabilities), the American Academy of Ophthalmology, the American Association for Paediatric Ophthalmology and Strabismus, and the American Association of Certified Orthoptists released a joint statement regarding learning disabilities, dyslexia, and vision therapy (McGregor 2014). It states that current research on visual therapy is of low scientific quality and that it does not provide conclusive evidence on the effects of visual therapy, with the exception of CI-treatments. It is also mentioned that reported improvements after visual therapy can often be attributed to the placebo effect. The results of this meta-analysis do indeed indicate that the improvement in reading performance after CI-treatment can be attributed to the placebo effect.

Contrary to popular believe, binocular vision anomalies are indeed not solely responsible for reading difficulties. Reported improvements in reading performance or other performance-related symptoms after visual therapy are often attributed to improvements in eye-related symptoms. However, current evidence seems to indicate that the placebo effect plays a major role in these improvements. Further research is needed to clarify the role of eye-related symptoms on the development of reading skills. Current research mainly focused on the short term improvements of reading performance in children who already experience reading difficulties. However, there are no long-term clinical trials that investigated whether preventative treatment of CI at a young age has a positive effect on the development of reading skills later in life.

Therefore, eventual future research should focus on the possible long-term effect on reading performance after CI-treatment in young children, as current research mainly investigated short-term effects. Reading is a process that develops during childhood, and as such short-term improvements do not show us the full picture. Consequently, a long-term, randomised, double-blind clinical trial with a placebo control group is the recommended study design for future research on this topic.

Due to the lack of available clinical research this meta-analysis only includes three clinical trials. Therefore, the validity of these results must be questioned by any clinician using this data to make clinical decisions. To support or contradict the findings in this meta-analysis further research is required.

6. Conclusion

The results of this meta-analysis indicate that the treatment of CI has little to no significant true effect on reading performance. However, CI-therapy seems to induce a small positive effect on reading performance, presumably caused by improvements in attention, motivation or other psychological factors (placebo effect). Therefore, clinicians and visual therapists should not explicitly state to patients that CI-treatments will improve reading performance and should prescribe such treatments mainly for the improvement of CI related symptoms.

Further research is required to fully understand what contributes to the improvements in reading performance after CI-therapy. However, this falls out of the scope of optometry as reading is a complex process that involves many areas other than the visual system.

Conflict of Interest Disclosure

The Author declares that there is no conflict of interest.

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Appendix A. Pre- and Post-treatment reading scores and results from the included trials.

Table A1. Mean total pre- and post treatment reading test scores from the study by Dusek et al. (2011).

Group, reading test ($n_{treatment}$)	**Mean total reading time in seconds (SD)**	
	First visit*	**Second visit****
Control-group, SRT (32)	130.88 (61.46)	127.03(60.59)
HTS-group, SRT (51)	113.98(48.86)	101.61(37.53)
Prism-group, SRT (51)	108.49 (48.68)	87.00(39.60)
	Mean reading error score (SD)	
	First visit*	**Second visit****
Control-group, SRT (32)	5.34(3.5)	4.66(2.9)
HTS-group, SRT (51)	4.53(3.06)	2.86(1.9)
Prism-group, SRT (51)	4.92(4.06)	2.12(1.9)

*Baseline reading test scores. **Reading test scores after 4weeks of HTS or prism therapy. Adapted from Dusek et al. (2011).

Table A2. Mean total pre- and post treatment reading test scores from the study by Scheiman et al. (2018).

Reading test ($n_{treatment}$)	**Mean change from baseline* (SD)**
GORT-4 accuracy (39)	0.00(1.78)
GORT-4 comprehension (43)	0.26(2.68)
GORT-4 fluency (39)	0.13(1.84)
GORT-4 rate (39)	0.26(1.83)
GORT-4 speed (36)	12.69(16.43)
TOSWRF composite (44)	1.50(8.92)
TOWRE composite (41)	1.83(8.09)
TOWRE phenomic decoding efficiency (42)	0.45(8.04)
TOWRE sight word efficiency (44)	2.18(8.99)
WIAT-II composite (44)	2.39(6.31)
WIAT-II pseudoword reading (44)	1.93(6.15)
WIAT-II reading comprehension (44)	4.16(10.08)
WIAT-II single word reading (44)	0.05(6.86)

*Mean change in reading test score from baseline after 16 weeks of OBVAT. Adapted from Scheiman et al. (2018).

Table A3. Mean total pre- and post treatment reading test scores from the CITT-ART (2019) study.

	Mean change from baseline* [95% confidence interval]	
Reading test ($n_{treatment}$, $n_{placebo}$)	**Treatment group**	**Placebo group**
AIMSweb R-CBM oral reading fluency (194,101)	-0.081[-0.14, -0.027]	-0.059[-0.13, 0.016]
AIMSweb Maze (194, 102)	0.48[0.39, 0.57]	0.45[0.33, 0.58]
GMRT 4th edition Reading comprehension (182,99)	-1.26[-3.11, 0.58]	-1.56[-4.07, 0.94]
WIAT-III listening comprehension (187,100)	2.65[1.41, 3.89]	3.88[2.19, 5.58]
WIAT-III oral reading fluency (179,100)	3.28[2.58, 3.97]	3.23[2.30, 4.15]
WIAT-III pseudoword decoding (187, 101)	1.08[0.28, 1.88]	0.75[-0.33,1.83]
WIAT-III reading comprehension (183, 100)	3.68[2.63, 4.73]	3.80[2.37, 5.22]
WIAT-III word reading (187,103)	1.69[0.93, 2.44]	2.63[1.62,3.63]

*Mean change in reading test score from baseline after 16 weeks of vergence/accommodative therapy or placebo therapy. Adapted from CITT-ART (2019).

Table A4. Between group* effect size from the CITT-ART (2019) study.

Reading test	**Effect size**
AIMSweb R-CBM oral reading fluency	-0.06
AIMSweb Maze	0.04
GMRT 4th edition Reading comprehension	0.02
WIAT-III listening comprehension	-0.14
WIAT-III oral reading fluency	0.01
WIAT-III pseudoword decoding	0.06
WIAT-III reading comprehension	-0.02
WIAT-III word reading	-0.19

*Effect size (Cohen's d) of the treatment difference between the V-A treatment group and the placebo group. Adapted from CITT-ART (2019)

Appendix B. Inclusion/Exclusion criteria, Scheiman et al. (2018).

B1. *"Inclusion criteria*

- Ages 9–17 years
- IQ better than 80 (KBIT-2)
- Best corrected visual acuity of 6/7.5 or better in each eye at distance and near
- Exophoria at near at least 4Δ greater than at far
- Insufficient positive fusional convergence (that is, failing Sheard's criterion or positive fusional vergence < 15Δ base-out blur or break)
- Receded near point of convergence of ≥ 6 cm break
- Appreciation of random dot stereopsis using a 500 seconds of arc target
- Convergence Insufficiency (CI) Symptom Survey score ≥ 16
- No previous CI treatment with office-based vergence/accommodative therapy with home reinforcement
- Willing to wear appropriate refractive correction
- Willing to discontinue use of base-in prism, bifocals or plus at near
- Have access to a computer to perform the computerised home therapy procedures
- If new glasses or a change in prescription is necessary, the subject must be willing to wear the new glasses and return in two weeks for eligibility testing
- Must have had a cycloplegic refraction within the last two months
- English as the primary language spoken at home or proficient in English as determined by the school
- ≥ 2Δ esophoria at distance
- Significant hearing loss
- Substance abuser as indicated by a response of two on either item 2 or item 105 of the Child Behaviour Checklist
- Developmental disability, attention deficit hyperactivity disorder, or learning disability diagnosis in children that in the investigator's
- discretion would interfere with the testing regimen

B2. Exclusion criteria

- Amblyopia (≥ 2 lines difference in best corrected visual acuity between the two eyes)
- Constant strabismus
- History of strabismus surgery
- High refractive error based on cycloplegic refraction: myopia ≥ 6.00 D sphere, hyperopia ≥ 5.00 D sphere, astigmatism ≥ 4.00 D
- Anisometropia ≥ 2.0 D spherical equivalent
- Prior refractive surgery
- Vertical heterophoria > 1Δ
- Systemic diseases known to affect accommodation, vergence and ocular motility such as: multiple sclerosis, Graves thyroid disease,
- myasthenia gravis, diabetes, Parkinson's disease
- Accommodative amplitude greater than 20 cm in either eye as measured by the Donder's push-up method
- Manifest or latent nystagmus
- CI secondary to acquired brain injury or any other neurological disorder"

Appendix C. Eligibility/exclusion criteria, CITT-ART (2019).

C1. *"Eligibility criteria*

- Age 9–14y
- Grades 3–8
- CISS score ≥16
- Exophoria at near (40 cm) at least 4D greater than at far (4 m)
- Receded near point of convergence of ≥6-cm break
- Insufficient positive fusional vergence at near (40 cm; i.e., failing Sheard's criterion or positive fusional vergence ≤15D BO break)
- Best-corrected distance (4 m) and near visual acuity (40 cm) of 20/25 or better in each eye
- Random-dot stereopsis appreciation of 500 seconds of arc or better (40 cm)
- Willing to wear refractive correction for any of the following
- uncorrected refractive errors (based on cycloplegic refraction within prior six months; correction must be worn for at least two weeks):
    - Myopia >−0.75 D spherical equivalent in either eye
    - Hyperopia >+2.00 D spherical equivalent in either eye
    - Anisometropia >0.75 D spherical equivalent
    - Astigmatism >1.00 D in either eye
        - Refractive error corrections adhered to the following guidelines: full hyperopic sphere power or symmetrically reduced by no more than 1.50 D, spherical equivalent myopia and spherical equivalent anisometropia within 0.75 D of full correction, and astigmatism within 0.75 D of full correction and axis within 6° for magnitudes of ≥1.00 D.
- Not wearing BI prism or plus add at near for two weeks before study enrolment and for duration of the study
- The timing of enrolment must allow a participant to be attending school at both the baseline and the 16-week outcome examination.
- English is primary language spoken at home, or the child is proficient in English as determined by the school.
- Parental permission to contact the child's teacher(s) for study purposes
- The parent and child understand the protocol and are willing to accept randomization.
- The parent does not expect the child to start any new ADHD medicine or change the dose of any currently taken ADHD medicine while the child is being treated in the study.

C2. Exclusion criteria

- Constant strabismus at distance or near
- Esophoria of ≥2D at distance
- Vertical heterophoria ≥2D at distance or near
- ≥2-Line interocular difference in best-corrected distance visual acuity
- Monocular near point of accommodation >20 cm (accommodative amplitude <5 D) as measured by push-up method
- Manifest or latent nystagmus
- Word reading subtest score <80 on WRAT-4
- KBIT-2 matrices subtest score <70

- History of strabismus, intraocular, or refractive surgery
- CI previously treated with any form of office-based vergence/accommodative therapy or home-based vergence therapy (e.g., computerized vergence therapy)
- CI associated with head trauma or known disease of the brain
- Diseases known to affect accommodation, vergence, or ocular motility such as multiple sclerosis, Graves orbitopathy, myasthenia gravis, diabetes mellitus, and Parkinson disease
- Inability to comprehend and/or perform any study-related test or procedure
- Speech-language disorder (e.g., stuttering) that would interfere with interpretation of digital recordings of reading tests
- Significant hearing loss
- Household member enrolled in the present CITT-ART or treated within the past six months with any form of office-based vergence/accommodative therapy or home-based vergence therapy (e.g., computerized vergence therapy)
- Household member is an eye care professional, ophthalmic technician, ophthalmology or optometry resident, or optometry student."

Appendix D. Pre- and Post treatment (cumulative) effect sizes

Table D1. Within-group (treatment) effect size of individual studies/reading tests and total within-group (treatment) cumulative weighted effect size.

Study, reading test/group	Effect Size*	SD	95% CI[$]	Relative weight**
Dusek et al. (2011), SRT/HTS error score	0,65	(0,20)	[0,26, 1,05]	2,20
Dusek et al. (2011), SRT/HTS reading speed	0,28	(0,20)	[-0,11, 0,67]	2,29
Dusek et al. (2011), SRT/Prism error score	0,88	(0,21)	[0,47, 1,28]	2,11
Dusek et al. (2011), SRT/Prism reading speed	0,48	(0,20)	[0,09, 0,87]	2,25
CITT-ART (2019), AIMSweb R-CBM oral reading fluency	0,61	(0,10)	[0,40, 0,81]	8,33
CITT-ART (2019), AIMSweb Maze	0,11	(0,10)	[-0,09, 0,3]	8,70
CITT-ART (2019), GMRT 4th edition Reading comprehension	0,04	(0,10)	[-0,17, 0,24]	8,18
CITT-ART (2019), WIAT-III listening comprehension	0,21	(0,10)	[0,01, 0,41]	8,35
CITT-ART (2019), WIAT-III oral reading fluency	0,31	(0,11)	[0,10, 0,52]	7,95
CITT-ART (2019),WIAT-III pseudoword decoding	0,08	(0,10)	[-0,12, 0,29]	8,39
CITT-ART (2019), WIAT-III reading comprehension	0,31	(0,10)	[0,11, 0,52]	8,12
CITT-ART (2019), WIAT-III word reading	0,12	(0,10)	[-0,08, 0,33]	8,38
Scheiman et al. (2018), GORT-4 accuracy	0,00	(0,22)	[-0,44, 0,44]	1,78
Scheiman et al. (2018), GORT-4 comprehension	0,02	(0,21)	[-0,40, 0,44]	1,96
Scheiman et al. (2018), GORT-4 fluency	0,02	(0,22)	[-0,42, 0,46]	1,78
Scheiman et al. (2018), GORT-4 rate	0,03	(0,22)	[-0,41, 0,47]	1,78
Scheiman et al. (2018), GORT-4 speed (words per minute)	0,18	(0,23)	[-0,28, 0,64]	1,64
Scheiman et al. (2018), TOSWRF composite	0,04	(0,21)	[-0,38, 0,45]	2,00
Scheiman et al. (2018), TOWRE composite	0,05	(0,22)	[-0,38, 0,48]	1,87

Scheiman et al. (2018), TOWRE phenomic decoding efficiency	0,01	(0,22)	[-0,41, 0,44]	1,91
Scheiman et al. (2018), TOWRE sight word efficiency	0,05	(0,21)	[-0,36, 0,47]	2,00
Scheiman et al. (2018), WIAT-II composite	0,08	(0,21)	[-0,33, 0,49]	2,00
Scheiman et al. (2018), WIAT-II pseudoword reading	0,07	(0,21)	[-0,35, 0,48]	2,00
Scheiman et al. (2018), WIAT-II reading comprehension	0,09	(0,21)	[-0,33, 0,5]	2,00
Scheiman et al. (2018), WIAT-II single word reading	0,00	(0,21)	[-0,41, 0,42]	2,00
Weighted Cumulative effect size (Fixed model)	0,21	(0,03)	[0,15, 0,27]	

*Effect size= Hedge's g, calculated with the Comprehensive Meta-Analysis software v3. **Weight attributed based on the total number of participant included in each subtest. $CI= Confidence interval

Table D2. Within-group (placebo) effect size of individual studies/reading tests and total within-group (placebo) cumulative weighted effect size.

Study, reading test/group	**Effect Size***	**SD**	**95% CI$**	**Relative weight****
CITT-ART (2019), AIMSweb R-CBM oral reading fluency	0,06	(0,14)	[-0,22, 0,33]	12,65
CITT-ART (2019), GMRT 4th edition Reading comprehension	0,11	(0,14)	[-0,17, 0,39]	12,38
CITT-ART (2019), Maze	0,58	(0,14)	[0,30, 0,86]	12,25
CITT-ART (2019), WIAT-III listening comprehension	0,24	(0,14)	[-0,04, 0,51]	12,44
CITT-ART (2019), WIAT-III oral reading fluency	0,26	(0,14)	[-0,02, 0,54]	12,42
CITT-ART (2019), WIAT-III pseudoword decoding	0,06	(0,14)	[-0,22, 0,33]	12,64
CITT-ART (2019), WIAT-III reading comprehension	0,31	(0,14)	[0,03, 0,59]	12,37
CITT-ART (2019), WIAT-III word reading	0,18	(0,14)	[-0,09, 0,46]	12,84
Weighted Cumulative effect size (Fixed model)	0,22	(0,05)	[0,13, 0,32]	12,65

*Effect size= Hedge's g, calculated with the Comprehensive Meta-Analysis software v3. **Weight attributed based on the total number of participants included in each subtest. $CI= Confidence interval