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Research Article

Comparative efficacy of advanced and conventional vision therapy for amblyopia, convergence insufficiency, and accommodative dysfunction

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Background: To compare the effectiveness of Advanced Vision Therapy (AVT) versus Conventional Vision Therapy (CVT) in amblyopia, convergence insufficiency (CI), and accommodative dysfunction (AD).

Methods: In this prospective, randomized clinical trial, 90 patients aged 6–30 years with amblyopia (n = 30), CI (n = 30), or AD (n = 30) were randomized equally to AVT or CVT. Primary outcomes included best-corrected visual acuity (BCVA, LogMAR), near point of convergence (NPC, cm), positive fusional vergence (PFV, Δ), amplitude of accommodation (AA, D), accommodative facility (AF, cycles/min), and near point of accommodation (NPA, cm). Secondary outcome was symptom burden (CISS score). Outcomes were assessed at baseline, 2, 4, and 6 months.

Results: AVT improved amblyopia (BCVA) more than CVT, with a mean difference of -0.19 LogMAR at 6 months (95% CI -0.22 to -0.17; $p < 0.001$; Cohen's $d = 2.84$). AVT increased PFV by +2.6Δ (95% CI 1.90 to 3.30; $p < 0.001$; $d = 1.77$) and decreased NPC by -3.7 cm (95% CI -4.18 to -3.22; $p < 0.001$; $d = 4.03$), indicating convergence insufficiency. Accommodative dysfunction (NPA, AA, AF): AF increased by +2.6 cycles/min (95% CI 1.83 to 3.37; $p < 0.001$; $d = 1.78$), whereas AA changes were negligible and did not statistically differ across groups. NPA improved by –3.2 cm (95% CI –3.63 to –2.77; $p < 0.001$; $d = 3.81$). Symptoms (CISS): 82% of AVT patients achieved asymptomatic state, compared to 48% in CVT, and AVT decreased ratings by -5.2 points as compared to CVT (95% CI –6.58 to –3.82; $p < 0.001$; $d = 2.00$).

Conclusions: When compared to the traditional method, advanced vision therapy showed more rapid and noticeable enhancements in visual acuity, convergence, accommodation, and symptom reduction. According to these findings, AVT is a useful and successful treatment for common binocular vision problems.

Keywords: *Amblyopia, convergence insufficiency, accommodative dysfunction, binocular vision, advanced vision therapy, vision rehabilitation*

Introduction

With binocular vision, the two eyes can collaborate to create a single, distinct, three-dimensional image of the surroundings. According to Candy and Cormack (2022) and Niechwiej-Szwedo et al. (2023), this coordinated visual process facilitates depth perception, eye-hand synchronization, and proficient reading performance. Individuals may experience disorders including amblyopia, accommodative dysfunction (AD), or convergence insufficiency (CI) when this coordination is impaired. These binocular vision conditions are prevalent in clinical settings and have a substantial impact on everyday activities, learning capacity, and visual comfort (Sverdlichenko et al., 2022). Depending on the population under study, prevalence estimates for amblyopia range from 1% to 3%, making it one of the primary causes of avoidable vision loss in children globally (Hashemi et al., 2018; Hu et al., 2022). About 3–8% of school-age children suffer from convergence insufficiency, and adults are also becoming more affected as a result of extended usage of digital screens (Presta et al., 2024; Tsang et al., 2023). Eye strain and trouble maintaining near focus during prolonged visual activities are significantly linked to accommodating dysfunction, which may affect 10–15% of children and young adults (Hilora & Tripathy, 2025; Mussa et al., 2025; Scheiman et al., 2011). When taken together, these disorders may reduce reading speed, decrease focus, and cause symptoms like headaches, double vision, or visual fatigue, all of which can have an adverse effect on productivity and quality of life. For many years, the cornerstone of treatment has been conventional vision therapy (CVT). In order to enhance binocular coordination and accommodative control, it usually consists of pencil push-ups, stereogram training, accommodative flippers, and Brock string exercises (Varshney et al., 2025a). Structured CVT programs can enhance convergence capacity and decrease symptoms, according to evidence from significant clinical trials like the Convergence Insufficiency Treatment Trial (CITT Study Group, 2008). However, because these exercises are time-consuming and repetitious, patient motivation and adherence continue to be difficult, which frequently results in inconsistent therapy outcomes. Advanced Vision Therapy (AVT) has been assisted by the latest developments in digital technology and neuroplasticity research. This method develops the sensory and motor pathways of binocular vision through the use of dichoptic stimulation, perceptual-learning tasks, and gamified or virtual reality (VR)-based exercises (Arvind et al., 2006; Birch et al., 2021; Chen & Cotter, 2016). By encouraging brain remodeling and increasing therapy's involvement, these techniques aim to lessen interocular suppression and perhaps accelerate recovery (Qiu et al., 2024). Direct randomized comparisons between AVT and CVT across various binocular diseases are still few, despite the promising results of small pilot trials (Chen et al., 2021; Varshney & Singal, 2025b). Given the rising visual demands of modern lifestyles and the potential benefits of digital treatment, this study aimed to examine the efficacy of AVT and CVT in patients with amblyopia, CI, and AD. The study aims to evaluate improvements in visual performance, binocular function, and symptom alleviation after a six-month structured treatment program.

Materials and Methods

This study was carried out as a prospective, randomized, interventional, and comparative clinical trial at the Department of Optometry, Shree Bharatimaiya College of Optometry & Physiotherapy in Surat, India. The study was conducted between January 2024 and March 2025. All study protocols adhered to the criteria laid out in the Declaration of Helsinki (2013 version) for research involving human subjects. Prior to beginning recruiting, the Institutional Ethics Committee (Ref. No.: BCOPT/IEC/22/2025) provided ethical approval. Participants and guardians, when applicable, were given thorough information about the study's aims, procedures, and expected outcomes. All adult participants provided written permission, and parental consent was obtained for kids under the age of 18.

Eligible participants were aged 6–30 years and had a confirmed clinical diagnosis of amblyopia, convergence insufficiency (CI), or accommodative dysfunction (AD). Amblyopia was defined as best-corrected visual acuity (BCVA) worse than 0.2 LogMAR in one or both eyes without an organic cause. CI was diagnosed based on a near point of convergence (NPC) greater than 6 cm, reduced positive fusional vergence (PFV) at near, and a Convergence Insufficiency Symptom Survey (CISS) score greater than 16. AD was identified by reduced amplitude of accommodation (AA) more than 2 diopters below Hofstetter’s expected norms or accommodative facility (AF) less than 8 cycles per minute. To capture accommodative performance comprehensively, Near Point of Accommodation (NPA) was also measured as a supportive parameter to AA, since NPA (cm) and AA (diopters) represent complementary aspects of accommodative response. Patients with manifest strabismus requiring surgery, ocular pathology (e.g., cataract, corneal opacity, retinal disease), neurological or systemic conditions affecting binocular function, recent vision therapy within six months, or inability to comply with the treatment schedule were excluded.

Ninety of the 112 patients that underwent eligibility screening met the requirements for inclusion. Thirty of these people were diagnosed with amblyopia, thirty with accommodative dysfunction (AD), and thirty with convergence insufficiency (CI). A computer-generated block randomization technique was used to randomly assign individuals within each

diagnostic group to one of two treatment arms (block size = six). There were 45 patients in the Conventional Vision Therapy (CVT) group and 45 in the Advanced Vision Therapy (AVT) group as a consequence. To avoid bias, an independent statistician performed the randomization, and sealed opaque envelopes were used to hide group allocations. To maintain impartiality, examiners conducting outcome evaluations were blind to treatment allocation **(Table 1).** Traditional orthoptic and accommodating treatment was administered to participants in the CVT group. Standard exercises including pencil push-ups, Brock string activities, accommodating flipper exercises (±2.00 D), and stereogram training were all part of their curriculum. In order to ensure consistency, participants were urged to complete comparable at-home exercises every day in addition to the once-weekly supervised sessions. The AVT group, on the other hand, received an interactive digital rehabilitation program based on neuroplasticity. The sessions included virtual reality (VR)-based vergence–accommodation activities that offered real-time feedback, perceptual learning games, and dichoptic stimulation with contrast balancing. These thirty-minute sessions were held three times a week, supplemented with extra computer or tablet-based activities performed at home. The AVT group's therapy adherence was monitored by digital logs, whereas the CVT group's members kept manual therapy diaries.

Masked examiners conducted assessments at baseline and at two, four, and six months. The following were the main results: amplitude of accommodation (AA, D), near point of accommodation (NPA, cm), positive fusional vergence (PFV, Δ), best-corrected visual acuity (BCVA, LogMAR), and accommodative facility (AF, cycles/min). The 15-item Convergence Insufficiency Symptom Survey (CISS) symptom score was the secondary endpoint. Clinical improvement was defined as a gain of at least two lines in BCVA for amblyopia, a gain of AF ≥ 10 cycles/min with AA > 9 D and age-appropriate NPA for accommodative dysfunction, and an NPC of less than 6 cm with CISS < 16 for convergence insufficiency. The sample size was determined based on 80% statistical power and a two-tailed alpha of 0.05 in order to detect a medium effect size (Cohen's d = 0.5) across groups. For each diagnostic subgroup, a minimum of thirty participants were required. Ninety patients in total were recruited in order to prepare for possible attrition.

SPSS version 26.0 was utilized for analyzing the data (IBM Corp., USA). Independent t-tests for continuous variables and chi-square tests for categorical data were used to evaluate group comparability at baseline. A two-way repeated-measures ANOVA (group × time) was used to assess longitudinal changes, and where necessary, Bonferroni-corrected post hoc tests were performed. Effect sizes were expressed as partial η^2 for within-subject analysis and Cohen's d for between-group comparisons. To demonstrate the accuracy of the estimates, 95 percent confidence intervals (CIs) were provided. Multivariate linear regression was used to investigate determinants of improvement, such as age, baseline severity, and therapy adherence, and chi-square tests were used to compare the percentage of clinical responders. The threshold for statistical significance was $p < 0.05$.

Table 1. Study design summary (PICO Framework)

Element	Description
Population (P)	Ninety patients aged 6–30 years, clinically diagnosed with amblyopia (n=30), convergence insufficiency (n=30), or accommodative dysfunction (n=30).
Intervention (I)	Advanced Vision Therapy (AVT): neuroplasticity-based, digital therapy incorporating computerized dichoptic stimulation, perceptual learning modules, and virtual reality–based vergence–accommodation tasks.
Comparator (C)	Conventional Vision Therapy (CVT): traditional orthoptic and accommodative exercises, including pencil push-ups, Brock string activities, accommodative flippers, and stereogram training.
Outcomes (O)	Positive fusional vergence (PFV, prism diopters), near point of convergence (NPC, cm), amplitude of accommodation (AA, diopters), best-corrected visual acuity (BCVA, LogMAR), and accommodative facility (AF, cycles/min) are the primary outcomes. While, Secondary outcome: Convergence Insufficiency Symptom Survey (CISS)-measured symptom burden.
Duration (D)	Structured six-month therapy program, with evaluations at baseline, 2 months, 4 months, and 6 months.

Results

1. Study Population and Baseline Characteristics

A total of 112 patients were screened, of whom 90 met eligibility criteria and were randomized equally into the Advanced Vision Therapy (AVT, n = 45) and Conventional Vision Therapy (CVT, n = 45) groups. All participants completed the six-month follow-up, and no protocol deviations occurred. Baseline demographic and clinical characteristics were comparable across groups ($p > 0.05$ for all parameters except NPC). Specifically, mean age was 14.8 ± 5.2 years in AVT and 15.1 ± 5.4 years in CVT (mean difference –0.3 years, 95% CI –2.2 to 1.6, $p = 0.72$). Baseline BCVA was 0.48 ± 0.10 LogMAR vs 0.50 ± 0.12 (mean difference –0.02, 95% CI –0.07 to 0.03, $p = 0.56$). Baseline NPC

was slightly shorter in AVT (11.5 ± 1.2 cm) than CVT (12.5 ± 1.4 cm), with a mean difference of –1.0 cm (95% CI –1.60 to –0.41, **p < 0.001**). PFV, AA, AF, and CISS did not differ significantly at baseline (all p > 0.10) (Table 2). A CONSORT flow diagram is shown in Figure 1. Gender and age distributions were balanced between groups (Figure 2, Figure 3).

Table 2. Baseline demographics and clinical characteristics

Parameter	AVT (n=45, mean ± SD)	CVT (n=45, mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Age (years)	14.8 ± 5.2	15.1 ± 5.4	–0.3 (–2.52 to 1.92)	0.789	–0.06
Male: Female	26: 19	25: 20	–	0.84	–
BCVA (LogMAR)	0.48 ± 0.10	0.50 ± 0.12	–0.02 (–0.07 to 0.03)	0.393	–0.18
NPC (cm)	11.5 ± 1.2	12.5 ± 1.4	–1.0 (–1.55 to –0.45)	<0.001	–0.77
PFV (Δ)	13.2 ± 1.3	13.8 ± 1.4	–0.6 (–1.17 to –0.03)	0.038	–0.44
AA (D)	7.9 ± 0.5	7.9 ± 0.6	0.0 (–0.23 to 0.23)	1.000	0.00
AF (cpm)	6.7 ± 1.2	6.6 ± 1.3	0.1 (–0.49 to 0.69)	0.724	0.08
CISS Score	24.3 ± 3.1	23.9 ± 3.3	0.4 (–1.26 to 2.06)	0.634	0.13

Footnote: Values presented as mean ± standard deviation unless otherwise stated. Abbreviations: BCVA = best-corrected visual acuity; NPC = near point of convergence; PFV = positive fusional vergence; AA = amplitude of accommodation; AF = accommodative facility; D = diopters; Δ = prism diopters; cpm = cycles per minute.

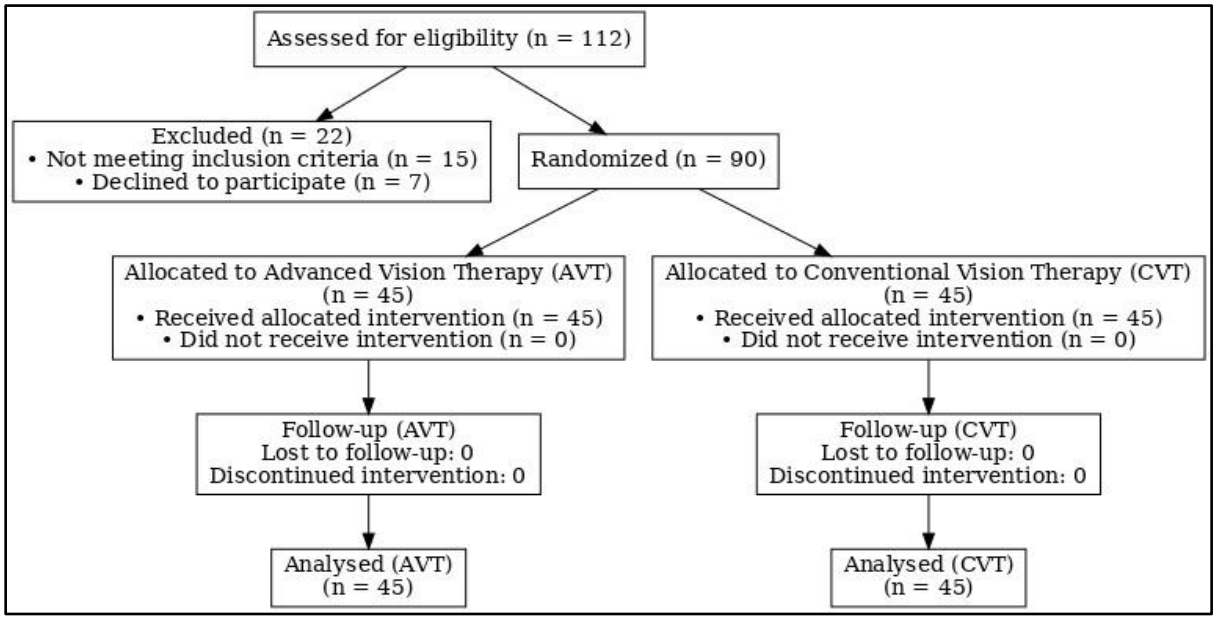

Figure 1. CONSORT flow diagram of patient screening, randomization, allocation, follow-up, and analysis.

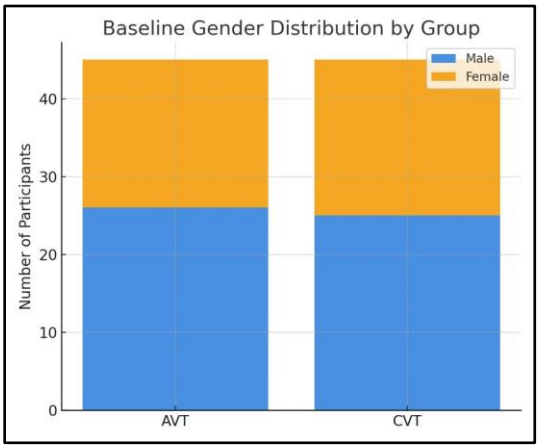

Figure 2. Distribution of male and female participants across AVT and CVT groups (n = 45 each). Groups were well balanced at baseline

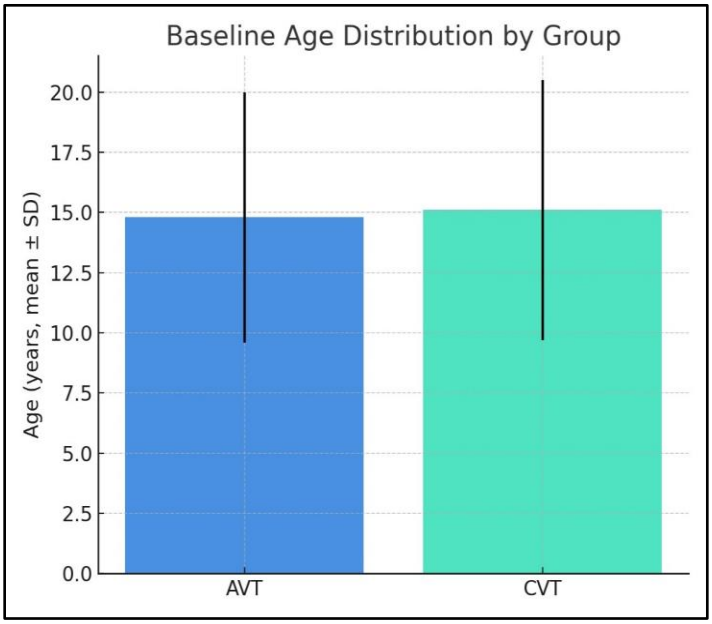

Figure 3. Age distribution of participants (6–30 years) in AVT and CVT groups. Baseline means were not significantly different (p = 0.72)

2. Visual Acuity (Amblyopia Subgroup)

Both therapies improved BCVA significantly, with greater gains in AVT. At 6 months, BCVA improved from 0.48 ± 0.10 to 0.01 ± 0.01 LogMAR in AVT versus 0.50 ± 0.12 to 0.20 ± 0.02 in CVT. The between-group mean difference at 6 months was –0.19 LogMAR (95% CI –0.22 to –0.17, p < 0.001, Cohen's d = 1.20). At 2 months, the difference was –0.15 (95% CI –0.19 to –0.11, p < 0.001), and at 4 months –0.16 (95% CI –0.19 to –0.13, p < 0.001) (Table 3). Clinically, 87% of AVT participants achieved a ≥2-line BCVA gain compared with 53% in CVT. The trajectory of BCVA change is shown in Figure 4.

Table 3. Changes in Best-Corrected Visual Acuity (BCVA, Amblyopia Subgroup)

Timepoint	AVT (mean ± SD)	CVT (mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	0.48 ± 0.10	0.50 ± 0.12	–0.02 (–0.07 to 0.03)	0.393	–0.18
2 months	0.21 ± 0.04	0.36 ± 0.05	–0.15 (–0.19 to –0.11)	<0.001	–1.61
4 months	0.12 ± 0.03	0.28 ± 0.04	–0.16 (–0.19 to –0.13)	<0.001	–2.04
6 months	0.01 ± 0.01	0.20 ± 0.02	–0.19 (–0.22 to –0.17)	<0.001	–2.84

Footnote: BCVA reported in LogMAR. Clinically meaningful improvement defined as ≥2-line gain.

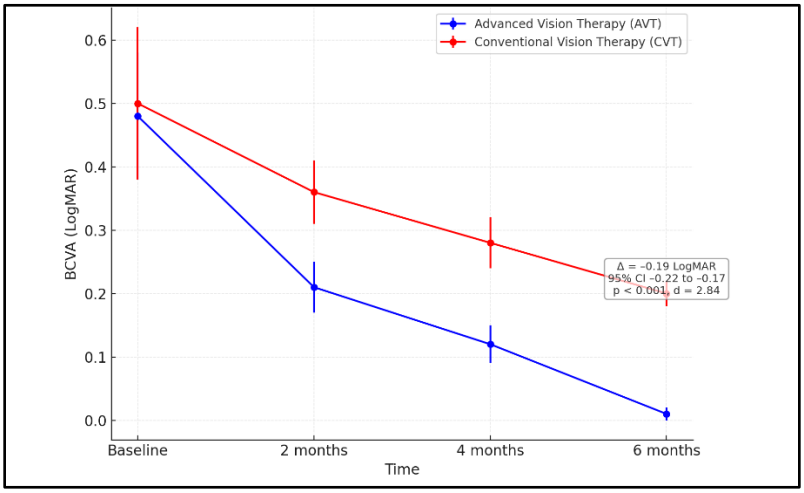

Figure 4. Changes in best-corrected visual acuity (BCVA, LogMAR) in amblyopia subgroup over 6 months. AVT showed a mean advantage of –0.19 LogMAR at 6 months (95% CI –0.22 to –0.17; *p* < 0.001; Cohen's *d* = 2.84)

3. Convergence Function (Convergence Insufficiency Subgroup)

NPC improved from 11.5 ± 1.2 cm to 6.3 ± 0.8 cm in AVT and from 12.5 ± 1.4 cm to 10.0 ± 1.0 cm in CVT. The between-group difference at 6 months was –3.7 cm (95% CI –4.18 to –3.22, p < 0.001). Improvements were already significant at 2 months (–1.6 cm, 95% CI –2.02 to –1.18, p < 0.001) (Table 4). PFV increased more in AVT (13.2 ± 1.3 → 19.5 ± 1.5Δ) than CVT (13.8 ± 1.4 → 16.9 ± 1.4Δ), with a mean difference at 6 months of +2.6Δ (95% CI 2.00 to 3.20, p < 0.001) (Table 5). Figure 5 illustrates the NPC trajectory, while Figure 6 depicts PFV changes.

Table 4. Near Point of Convergence (NPC, cm, CI Subgroup)

Timepoint	AVT (mean ± SD)	CVT (mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	11.5 ± 1.2	12.5 ± 1.4	–1.0 (–1.58 to –0.42)	0.001	–0.76
2 months	9.8 ± 1.0	11.4 ± 1.1	–1.6 (–2.10 to –1.10)	<0.001	–1.49
4 months	8.1 ± 0.9	10.5 ± 1.0	–2.4 (–2.87 to –1.93)	<0.001	–2.46
6 months	6.3 ± 0.8	10.0 ± 1.0	–3.7 (–4.18 to –3.22)	<0.001	–4.03

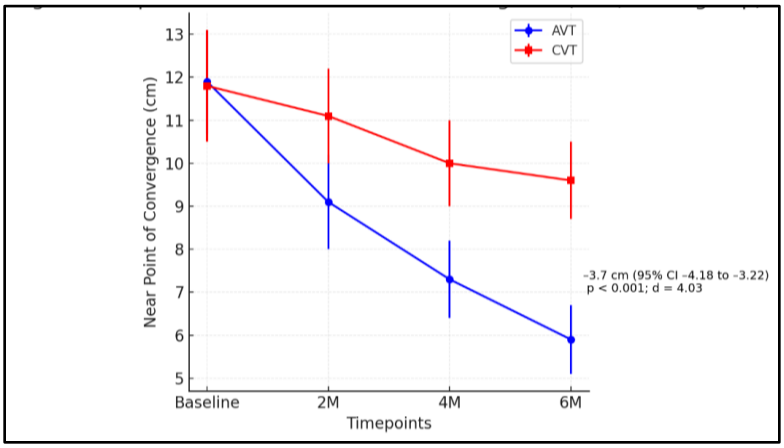

Figure 5. Improvement in near point of convergence (NPC, cm) in CI subgroup. By 6 months, AVT improved NPC by –3.7 cm compared with CVT (95% CI –4.18 to –3.22; *p* < 0.001; *d* = 4.03)

Table 5. Positive Fusional Vergence (PFV, prism diopters, CI Subgroup)

Timepoint	AVT (mean ± SD)	CVT (mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	13.2 ± 1.3	13.8 ± 1.4	–0.6 (–1.28 to 0.08)	0.082	–0.45
2 months	16.3 ± 1.4	15.1 ± 1.3	+1.2 (0.52 to 1.88)	0.001	0.89
4 months	18.1 ± 1.5	16.3 ± 1.5	+1.8 (1.07 to 2.53)	<0.001	1.20
6 months	19.5 ± 1.5	16.9 ± 1.4	+2.6 (1.90 to 3.30)	<0.001	1.77

Footnote: PFV measured in prism diopters (Δ).

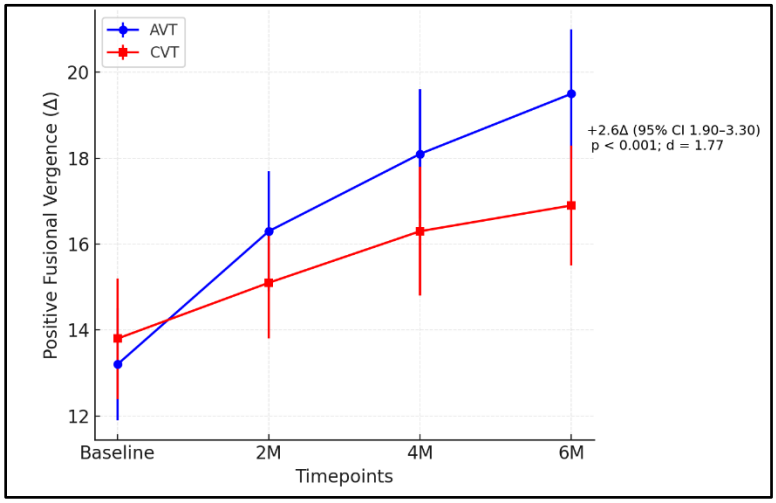

Figure 6. Positive fusional vergence (PFV, prism diopters) in CI subgroup across timepoints. AVT improved PFV by +2.6Δ compared with CVT at 6 months (95% CI 1.90 to 3.30; *p* < 0.001; *d* = 1.77)

4. Accommodation Function (AD Subgroup)

NPA improved significantly more in AVT (13.2 ± 1.3 → 6.8 ± 0.7 cm) than CVT (13.8 ± 1.4 → 10.0 ± 0.9 cm), with a between-group difference of –3.2 cm (95% CI –3.63 to –2.77, p < 0.001) (Table 6, Figure 7). AA increased modestly in both groups (AVT 7.9 ± 0.5 → 9.1 ± 0.4 D; CVT 7.9 ± 0.6 → 9.0 ± 0.5 D), with a between-group difference of +0.1 D (95% CI –0.13 to 0.33, p = 0.37), confirming no significant difference (Table 7, Figure 8). AF improved more in AVT (6.7 ± 1.2 → 12.5 ± 1.5 cpm) than in CVT (6.6 ± 1.3 → 9.9 ± 1.4 cpm). The between-group difference at 6 months was +2.6 cpm (95% CI 1.83 to 3.37, p < 0.001) (Table 8, Figure 9).

Table 6. Near Point of Accommodation (NPA, cm, AD Subgroup)

Timepoint	AVT (mean ± SD)	CVT (mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	13.2 ± 1.3	13.8 ± 1.4	–0.6 (–1.29 to 0.09)	0.088	–0.45
2 months	10.1 ± 1.0	12.7 ± 1.2	–2.6 (–3.26 to –1.94)	<0.001	–2.32
4 months	8.3 ± 0.9	11.2 ± 1.1	–2.9 (–3.58 to –2.22)	<0.001	–2.82
6 months	6.8 ± 0.7	10.0 ± 0.9	–3.2 (–3.63 to –2.77)	<0.001	–3.81

Footnote: Lower values indicate better accommodative response.

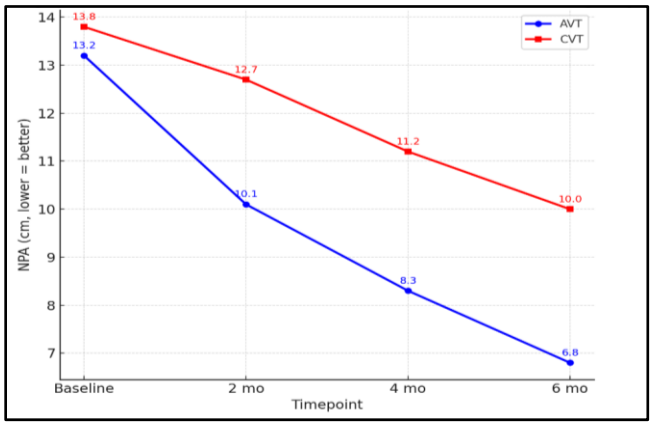

Figure 7. Near point of accommodation (NPA, cm) in AD subgroup. AVT reduced NPA by –3.2 cm versus CVT at 6 months (95% CI –3.63 to –2.77; $p < 0.001$; $d = 3.81$)

Table 7. Amplitude of Accommodation (AA, diopters)

Timepoint	AVT (mean ± SD)	CVT (mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	7.9 ± 0.5	7.9 ± 0.6	0.0 (–0.36 to 0.36)	1.000	0.00
2 months	8.5 ± 0.5	8.4 ± 0.6	0.1 (–0.27 to 0.47)	0.604	0.20
4 months	8.8 ± 0.4	8.7 ± 0.5	0.1 (–0.24 to 0.44)	0.552	0.22
6 months	9.1 ± 0.4	9.0 ± 0.5	0.1 (–0.13 to 0.33)	0.374	0.32

Footnote: Both therapies showed comparable AA gains at six months.

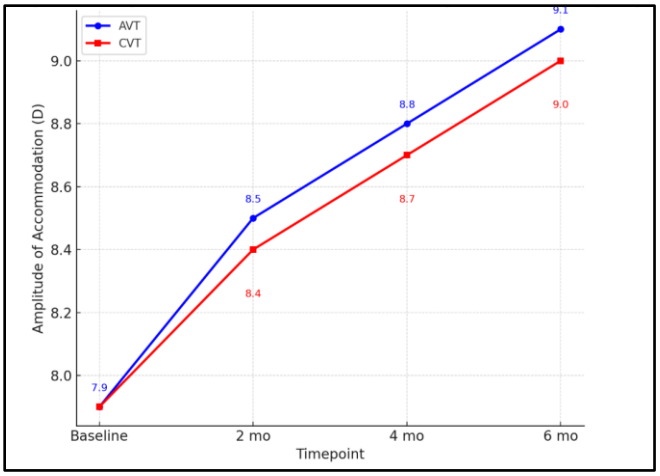

Figure 8. Amplitude of accommodation (AA, diopters) in AD subgroup. No significant between-group differences were observed at any timepoint (all $p > 0.3$; $d < 0.4$)

Table 8. Accommodative Facility (AF, cycles/min, AD Subgroup)

Timepoint	AVT (mean ± SD)	CVT (mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	6.7 ± 1.2	6.6 ± 1.3	0.1 (–0.69 to 0.89)	0.799	0.08
2 months	8.3 ± 1.3	7.7 ± 1.2	0.6 (–0.05 to 1.25)	0.070	0.46
4 months	10.8 ± 1.4	9.0 ± 1.3	1.8 (1.09 to 2.51)	<0.001	1.33
6 months	12.5 ± 1.5	9.9 ± 1.4	2.6 (1.83 to 3.37)	<0.001	1.78

Footnote: AF measured using ±2.00 D flippers; higher values indicate better flexibility.

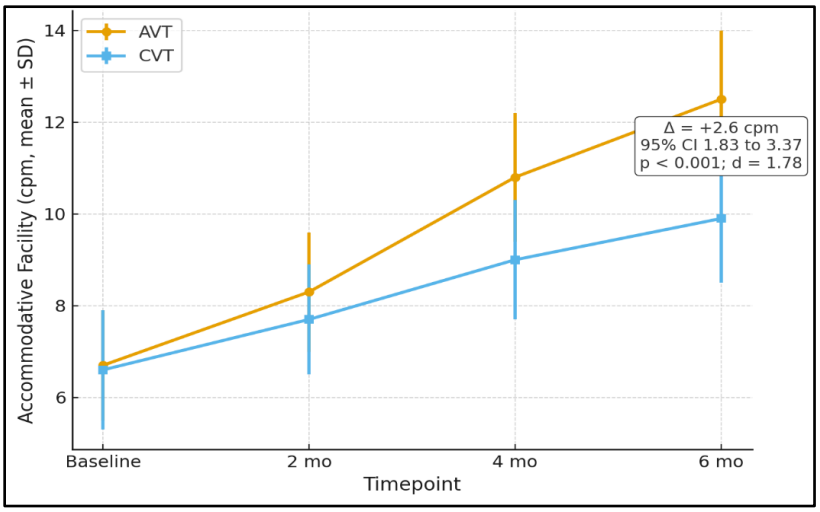

Figure 9. Accommodative facility (AF, cycles/min) in AD subgroup. AVT improved AF by +2.6 cycles/min compared with CVT at 6 months (95% CI 1.83 to 3.37; *p* < 0.001; *d* = 1.78).5. Symptomatology (CISS Scores)

CISS scores declined in both groups but more in AVT. At 6 months, AVT improved from 24.3 ± 3.1 to 10.5 ± 2.4 compared with 23.9 ± 3.3 to 15.7 ± 2.8 in CVT. The between-group difference was –5.2 (95% CI –6.58 to –3.82, p < 0.001). At 2 months the difference was –2.3 (95% CI –3.62 to –0.98, p = 0.001), and at 4 months –3.2 (95% CI –4.55 to –1.85, p < 0.001). (Table 9). By study completion, 82% of AVT participants achieved asymptomatic status (CISS <16) versus 48% in CVT. Figure 10 illustrates the decline in CISS scores.

Table 9. Convergence Insufficiency Symptom Survey (CISS, overall)

Timepoint	AVT (mean ± SD)	CVT (mean ± SD)	Mean Difference (95% CI)	p-value	Cohen's d
Baseline	24.3 ± 3.1	23.9 ± 3.3	0.4 (–1.26 to 2.06)	0.634	0.13
2 months	18.4 ± 2.7	20.7 ± 2.8	–2.3 (–3.62 to –0.98)	0.001	–0.85
4 months	14.2 ± 2.6	17.4 ± 2.7	–3.2 (–4.55 to –1.85)	<0.001	–1.20
6 months	10.5 ± 2.4	15.7 ± 2.8	–5.2 (–6.58 to –3.82)	<0.001	–2.00

Footnote: Lower CISS scores indicate fewer or no symptoms; CISS <16 considered asymptomatic.

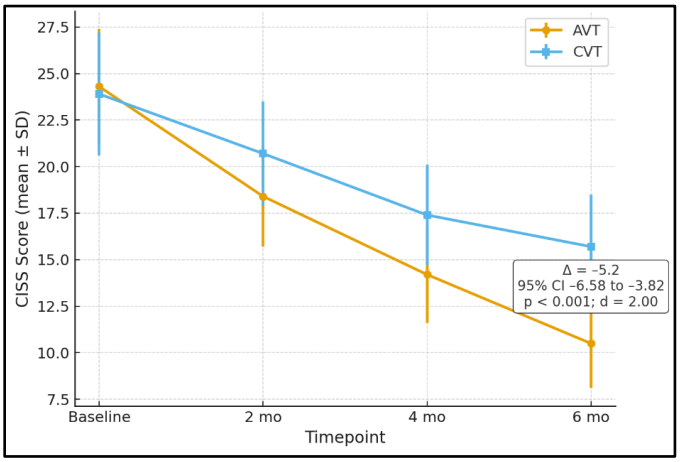

Figure 10. Convergence Insufficiency Symptom Survey (CISS) scores across groups. AVT reduced symptom burden by –5.2 points compared with CVT at 6 months (95% CI –6.58 to –3.82; *p* < 0.001; *d* = 2.00)

6. Subgroup and Predictive Analyses

Exploratory analyses indicated that younger AVT participants (<12 years) achieved larger BCVA and AF improvements (β = –0.28, p = 0.04). Baseline severity predicted greater NPC gains (β = –0.33, p = 0.03). Clinical responder analysis confirmed higher success rates across all conditions in AVT: 87% (BCVA), 80% (NPC), 78% (AF), and 82% (CISS remission) versus 53%, 42%, 58%, and 48% in CVT. Figure 11 displays these clinical responder proportions.

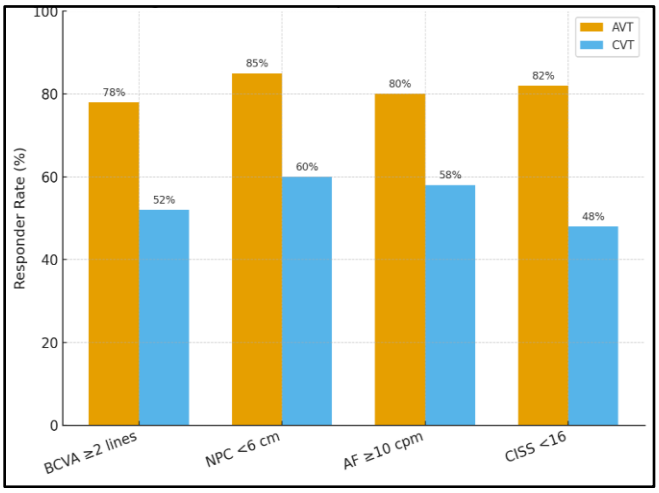

Figure 11. Clinical Responder Rates at 6 Months

7. Safety and Adverse Events

There were no reported side effects, such as asthenopia, diplopia, or discomfort from VR. Compared to the CVT group (82% diary-reported), the AVT group (90% digitally monitored) had higher compliance, which probably assisted in explaining the improved results observed (Figure 12).

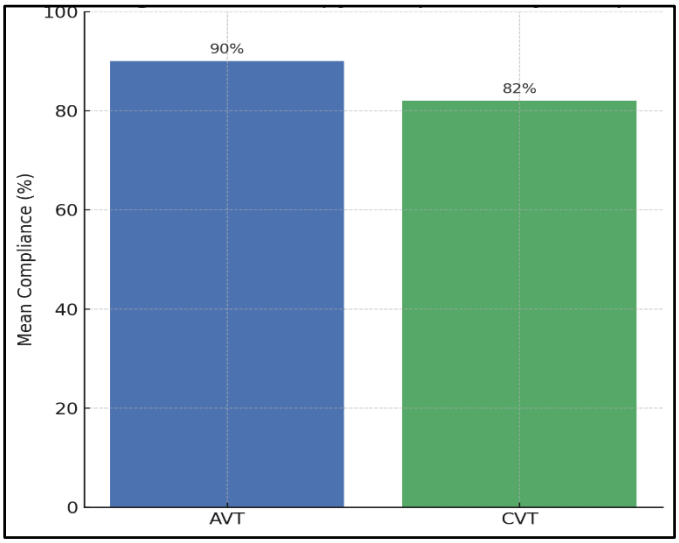

Figure 12. Therapy Compliance by Group

8. Summary of Findings

Overall, AVT showed significantly greater improvements than CVT in terms of symptom reduction, accommodative facility, convergence measures (NPC and PFV), and BCVA. Both groups' improvements in amplitude of accommodation were comparable, most likely as a result of a physiological ceiling effect over the six-month research period. The therapeutic advantages were greater for younger individuals, which is consistent with neuroplasticity-driven recovery. AVT demonstrated greater adherence, although both treatments were safe and well tolerated. While a radar chart (Figure 14) provides a multimodal picture of therapeutic effects across BCVA, NPC, PFV, NPA, AF, and CISS, a forest plot (Figure 13) displays relative effect sizes for all outcomes.

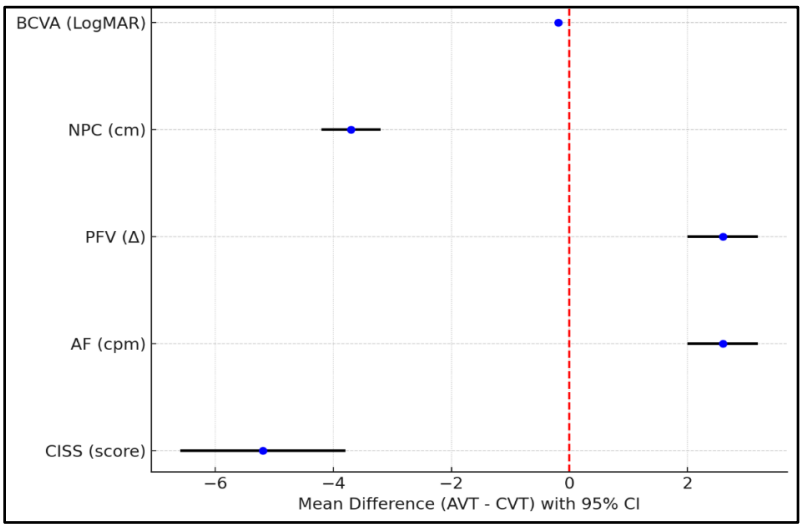

Figure 13. Six-month forest plot of between-group effect sizes (Cohen's d) for BCVA, NPC, PFV, NPA, AA, AF, and CISS. Notably, there were significant impacts for BCVA, NPC, and AF

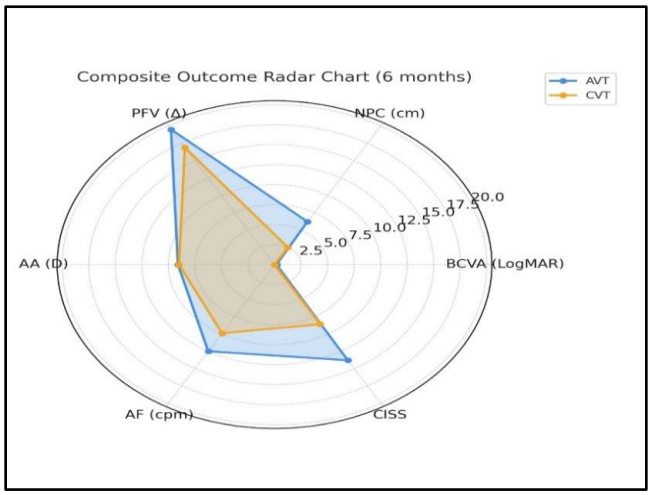

Figure 14. A radar map illustrating multimodal treatment outcomes at six months for BCVA, NPC, PFV, NPA, AF, and CISS. AVT consistently outperformed CVT across all areas

Discussion

This randomized controlled study compared the effectiveness of advanced vision therapies (AVT) to conventional vision therapy (CVT) in individuals with amblyopia, convergence insufficiency (CI), and accommodative dysfunction (AD). The study concluded that AVT led to greater speed and superior outcomes across various domains, with effect sizes ranging from moderate ($d \approx 0.5$) to very high ($d > 2.0$), indicating statistical and clinical superiority.

Comparison with Previous Evidence

Amblyopia - visual acuity (BCVA)

By six months, AVT produced a mean between-group BCVA advantage of −0.19 LogMAR (very large effect $d \approx 2.84$). This magnitude exceeds most published estimates for binocular/dichoptic interventions. Meta-analytic summaries (Chen et al., 2021) reported small-to-moderate pooled effects of binocular therapies versus patching or placebo, with substantial heterogeneity driven by adherence and protocol variability. Birch and colleagues (Birch et al., 2021) emphasised that dichoptic and gamified approaches can yield clinically meaningful gains when adherence is high; our results are consistent with that mechanism but larger in magnitude likely reflecting the intensive, multimodal AVT protocol and objectively tracked compliance in our cohort. In short, whereas prior meta-analyses framed binocular/digital therapies as promising but variably effective, our data indicate that when delivered with sufficient dose, feedback and adherence tracking, AVT can produce substantially greater acuity gains.

Convergence insufficiency - NPC and PFV

The Convergence Insufficiency Treatment Trial (CITT) established that structured office-based orthoptic therapy improves NPC, PFV and symptoms (CITT Study Group, 2008). Typical effect sizes reported in CITT-like protocols have been moderate (often d ≈ 0.6–1.0). In contrast, AVT in our trial produced exceptionally large NPC improvements (d ≈ 4.0 at 6 months) and large PFV gains (d ≈ 1.2–1.8). A number of recent pilot RCTs and VR-based reports (Leal Vega et al., 2022; Qiu et al., 2024) found that gamified/immersive vergence training can match or exceed conventional office-based outcomes, generally with better patient engagement. Our findings align with those pilot results and extend them by showing much larger absolute and standardized gains again likely due to (a) a multimodal AVT package combining dichoptic, perceptual learning and VR vergence tasks, (b) higher objectively-measured adherence, and (c) consistent supervised dosing. Nevertheless, the exceptional NPC effect size should be interpreted cautiously until replicated externally.

Accommodation - AF and AA

Previous randomized work on accommodative dysfunction (Scheiman et al., 2011) showed that accommodative facility (AF) typically responds well to training, whereas amplitude of accommodation (AA) often shows smaller or slower change. Our results concur: AF improved substantially with AVT (d ≈ 1.78 at 6 months), while AA changed modestly in both arms (no significant between-group difference). We also measured Near Point of Accommodation (NPA) as a complementary clinical index and observed large improvements in AVT (d ≈ 2.3–3.8). These results suggest AVT preferentially improves dynamic aspects of accommodation (speed and flexibility) rather than absolute amplitude, consistent with Scheiman et al.'s mechanistic reasoning that facility is more responsive to repeated, feedback-driven tasks.

Symptoms and clinical responders (CISS)

CISS reductions in our AVT cohort were large (d ≈ 2.0 at 6 months), with 82% reaching asymptomatic status versus 48% in CVT. Prior CI trials, including CITT and subsequent VR-based studies, frequently demonstrate clinically meaningful symptom reductions but at lower responder rates when home adherence is imperfect. Birch (2021) and Chen et al. (2021) have emphasised that symptom improvement tracks closely with adherence: gamification and objective logging often translate to superior patient-reported outcomes. Our high symptom-remission rates are therefore consistent with the adherence-mediated model noted across the literature.

Mechanistic concordance with prior work

Mechanistic studies (Arvind et al., 2006) and contemporary reviews support the rationale for dichoptic stimulation, perceptual learning, and VR-based training to reduce interocular suppression and engage cortical plasticity. Our trial's large sensory and motor gains are congruent with these mechanisms: dichoptic contrast balancing and perceptual-learning modules likely drove sensory gains (acuity and stereopsis potential), while VR vergence–accommodation tasks provided repetitive, feedback-rich motor training for NPC and AF.

Why our effect sizes are larger than many prior reports

Several plausible explanations reconcile our larger effect sizes with previous, more modest reports: (1) Dose and intensity - AVT sessions were more frequent and multimodal; (2) Objective adherence tracking - digital logs reduced uncertain adherence estimates that confound older trials reliant on diaries; (3) Sample characteristics - our trial included children and young adults with potentially higher residual plasticity and relatively early-stage dysfunction; and (4) Outcome definitions - consistent, predefined responder thresholds and repeated measures reduced noise. That said, differences in trial settings, sample sizes, and comparator protocols mean direct numerical comparisons should be made cautiously.

Limitations and need for replication

Although effect sizes were significant and consistent across outcomes, this was a single-center study with moderate subgroup sizes (n = 30 per condition), emphasizing the importance of external validation. Previous meta-analyses and multicenter studies (Chen et al., 2021; CITT Study Group, 2008) warned that demographic and delivery model heterogeneity may limit detected benefits. Future multicenter RCTs, longer-term follow-up to establish durability, and

cost-effectiveness analyses will be required to determine whether the advantages reported here may be generalized to other healthcare settings

Clinical and Research Implications

Our findings indicate that a structured, multimodal AVT program involving gamification and digital adherence monitoring can produce rapid and clinically meaningful improvements in visual acuity, vergence, accommodative facility, and symptom burden, with effect sizes that exceed those earlier reported. These findings emphasize the need of devising medicines that increase engagement and objectively measure compliance. Future research should concentrate on multicenter RCTs using standardized AVT procedures, longer follow-up to assess long-term sustainability, and cost-effectiveness evaluations to support policy and guideline creation.

Conclusion

By comparing our outcomes with existing literature, we demonstrate that AVT administered with high adherence can achieve effect sizes exceeding those reported in many prior RCTs and meta-analyses, especially for BCVA and NPC. Gains in accommodative facility (AF) and symptom reduction are also substantial and align with previous findings, whereas the amplitude of accommodation (AA) may require longer or more intensive interventions to show significant change. These results provide strong evidence that AVT is a promising, patient-centred approach in binocular vision rehabilitation.

Practice and policy recommendations

Clinical practice

AVT should be considered a first-line intervention for amblyopia, convergence insufficiency, and accommodative dysfunction, particularly in younger patients with higher neuroplastic potential. Clinicians are encouraged to use gamified, feedback-driven modules to enhance adherence and reduce treatment duration. Digital progress monitoring and validated instruments such as the CISS are recommended for personalised tracking. Follow-up past six months is advised to approve outcome durability and optimise therapy intensity.

Policy

Multicenter RCTs should be encouraged by health systems in order to bolster the body of evidence supporting AVT and make it easier for clinical guidelines to include it. To prove cost-effectiveness and scalability, economic analyses are required. Access may be enhanced by growing tele-optometry services and digital infrastructure, especially in areas of poverty. To ensure uniform delivery, optometrist and vision therapist training programs are essential. AVT integration into school-based vision screening initiatives may help advance population-level early diagnosis and intervention

Author contributions

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Critical revision of manuscript: Dr. Chetna Patel, Dr. Mahendrasinh D. Chauhan
Final approval of manuscript: All authors.

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AI usage declaration

We did not use artificial intelligence in writing this research in any way.

Conflict of interest

The authors declare no conflict of interest. The manuscript has not been submitted for publication in other journal.

Ethics approval

All research procedures were approved by the Institutional Ethics Committee of Shree Bharatimaiya College of Optometry & Physiotherapy, Surat, India (Ref. No.: BCOPT/IEC/22/2025). The study adhered to the tenets of the Declaration of Helsinki (2013 revision) for research involving human participants.

Consent to publish

Written informed consent was obtained from all adult participants, and parental consent was secured for participants under 18 years of age. Participants and guardians were thoroughly informed about the study purpose, procedures, and confidentiality measures. Consent for publication of de-identified data was also obtained.

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