


Visual Training for Myopia Control: An Independent and Additive Inhibitor of Axial Growth

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Purpose: To evaluate the efficacy of visual training (VT) in retarding axial elongation in myopic children and to determine its additive clinical value when combined with standard myopia control modalities, including orthokeratology (OK), defocus spectacles (DS), and low-concentration atropine (LCA).

Methods: This is a retrospective, multicenter, self-controlled cohort study. A total of 208 myopic children (mean age 9.73 ± 2.08 years) who underwent a structured visual training program were included. Subjects were stratified into five subgroups based on concurrent treatments: VT monotherapy, VT+DS, VT+OK, VT+DS+LCA, and VT+OK+LCA. Annualized axial elongation rates were calculated for the pre-training (baseline) and post-training intervals. The primary outcome was the reduction in axial elongation rate.

Results: The mean axial elongation rate significantly attenuated from a baseline of 0.38 ± 0.34 mm/year to 0.23 ± 0.30 mm/year following the intervention ($P < 0.001$), representing a mean reduction of 0.15 ± 0.31 mm/year. There were no statistically significant differences in the magnitude of rate reduction among the five subgroups ($P = 0.826$), indicating that VT confers a consistent additive benefit independent of concurrent optical or pharmacological therapies. Pearson correlation analysis revealed a good positive association between baseline progression rate and treatment efficacy ($r = 0.57$, $P < 0.001$), suggesting that children with faster initial progression derived the greatest therapeutic benefit.

Conclusion: Visual training effectively slows axial elongation, shifting pathological growth trajectories toward physiological norms. It functions as a universal adjunctive therapy, providing robust and independent protective effects regardless of whether the patient is using OK lenses, defocus spectacles, or atropine. These findings support the use of visual training as a priority “rescue therapy” for rapid progressors.

Keywords: myopia, visual training, axial elongation, binocular vision, adjunctive therapy

Introduction

Myopia has emerged as a significant global public health concern, with its prevalence rising at an alarming rate. It is projected that by 2050, nearly half of the world's population will be myopic, with approximately 10% suffering from high myopia.¹ The primary pathological concern associated with myopia is excessive axial elongation, which dramatically increases the risk of vision-threatening complications such as myopic maculopathy, retinal detachment, and glaucoma.^{2–5} Consequently, slowing axial elongation has become the cornerstone of modern pediatric myopia management.

Currently, the mainstream interventions for myopia control include optical strategies—such as orthokeratology (OK) lenses and peripheral defocus spectacles, and pharmacological agents like low-concentration atropine.^{6–8} While these modalities have demonstrated efficacy, a subset of children, often termed “rapid progressors”, continues to exhibit

substantial axial elongation despite adherence to these treatments.⁹ This variability in treatment response suggests that current optical and pharmacological approaches may not address all underlying mechanisms driving myopia progression.

Emerging evidence suggests that binocular vision anomalies, such as accommodation lag, high AC/A ratio, and vergence dysfunction, may play a pivotal role in the onset and progression of myopia.^{10–29,303} The “retinal defocus theory” posits that hyperopic defocus drives axial growth; however, unstable accommodation or poor oculomotor control can induce transient retinal blur, potentially confounding the protective effects of optical devices.¹¹ Visual training (VT), a structured program designed to improve neuromuscular control and sensory fusion, has been widely used to treat strabismus and amblyopia. Recently, interest has grown regarding its potential as an adjunctive therapy for myopia control.¹² By normalizing accommodation dynamics and vergence flexibility, VT aims to optimize retinal image quality and reduce visual stress.

Despite the theoretical rationale, clinical evidence quantifying the effect of visual training on axial elongation—particularly in combination with established myopia control methods—remains sparse. Most existing studies focus on changes in refractive error or accommodative parameters rather than axial length, the gold standard metric for progression.^{12,13} Furthermore, it remains unclear whether visual training offers additional benefits when added to standard treatments like OK lenses or atropine.

To address this gap, this retrospective cohort study evaluated the efficacy of a structured visual training program in retarding axial elongation among myopic children. Specifically, we aimed to quantify the reduction in axial growth rate following VT intervention; assess whether VT provides an additive benefit across different concurrent treatment modalities (OK lenses, defocus spectacles, and atropine); and identify patient characteristics that predict the most significant therapeutic response.

Materials and Methods

Study Design and Ethical Approval

This retrospective observational study was conducted at two clinical centers: Beijing Visionly Plus Eye Hospital and Beijing New Vision Eye Hospital (Beijing, China). The study adhered to the ethical standards laid out by the Declaration of Helsinki. Ethical clearance was obtained from the Beijing New Vision Eye Hospital’s Ethics Committee and Institutional Review Board (IRB) (approval no. 2025005). Due to its retrospective nature utilizing anonymous data, the study was granted a waiver of informed consent by the IRB. All patient data were de-identified prior to statistical analysis. The data collection period encompassed patients undergoing visual training for myopia control between Jan 1, 2024, and Jan 1, 2025.

Participants and Selection Criteria

A total of 208 myopic children (208 eyes) were included in the final analysis. Inclusion criteria were as follows: (1) age between 5 and 15 years at the commencement of training; (2) diagnosis of myopia with a spherical equivalent (SE) refraction ≤ -0.50 D; (3) completion of a structured visual training program (attending at least 80% of the scheduled in-office sessions and demonstrating adherence to the prescribed home-based exercises); (4) availability of complete axial length (AL) data at three critical time points: at least two examinations prior to training (to establish baseline progression rate) and at least one examination following the training intervention. Exclusion criteria included: (1) presence of other ocular pathologies (eg., amblyopia, strabismus, congenital cataract); (2) history of ocular surgery or trauma; (3) systemic diseases affecting ocular health; (4) any corneal or ocular surface pathology; or (5) incomplete or inconsistent follow-up records preventing the calculation of annualized progression rates. To avoid potential bias arising from the correlation between eyes, only the right eye was selected for analysis.

Myopia Control Modalities and Grouping

To evaluate the independent and adjunctive effects of visual training, subjects were categorized into five subgroups based on their concurrent myopia control modalities utilized during the observation period: (1) Visual Training Monotherapy: Subjects receiving visual training only, with single-vision spectacles (SVS) or no optical correction. (2) Defocus

Spectacles: Subjects wearing peripheral defocus management spectacles (eg., DIMS, HAL technology). (3) Defocus Spectacles + Atropine: Combination of defocus spectacles and low-concentration atropine (0.01%). (4) Orthokeratology (OK) Lens: Subjects wearing overnight orthokeratology lenses. (5) OK Lens + Atropine: Combination of OK lenses and low-concentration atropine.

Visual Training Protocol

The visual training intervention targeted binocular vision anomalies, including accommodation and vergence dysfunctions. The regimen consisted of in-office training sessions supplemented by home-based exercises. The core modules included: (1) Static Ocular Alignment: Exercises designed to maintain stable fixation and alignment. (2) Dynamic Ocular Alignment: Tasks focused on accurate saccadic and pursuit eye movements to improve dynamic gaze control. (3) Fusional Convergence: Training aimed at strengthening positive fusional vergence (PFV) reserves. (4) Dynamic Stereopsis: Activities requiring depth perception judgments of moving stimuli. (5) Coarse (Large-range) Stereopsis: Stimulation using large-disparity targets to engage global stereoscopic processing (Table 1).

Data Collection and Outcome Measures

The primary outcome measure was the rate of Axial Length (AL) elongation. AL was measured using partial coherence interferometry (IOLMaster 700, Carl Zeiss Meditec, Germany). The Annualized Axial Elongation Rate (mm/year) was calculated for two distinct periods: Pre-training Rate: Calculated based on the AL change over the period immediately preceding the start of visual training. Post-training Rate: Calculated based on the AL change from the start of training to the last follow-up visit. The efficacy of the intervention was quantified as the Reduction in Elongation Rate = Pre-training Rate - Post-training Rate. A positive value indicates a slowing of myopia progression (therapeutic benefit).

Statistical Analysis

Although training was binocular, only data from the right eye were analyzed to ensure independence. Statistical analyses were performed using Python (incorporating the *SciPy* and *Pandas* libraries). Descriptive statistics were presented as mean \pm standard deviation (SD) for continuous variables and frequency (percentage) for categorical variables. The normality of data distribution was assessed using the Shapiro–Wilk test. Since the differences in axial elongation rates followed a non-normal distribution: The Wilcoxon Signed-Rank Test was used to compare paired data (Pre-training vs. Post-training rates) for the entire cohort. The Kruskal–Wallis *H*-Test was employed to compare the magnitude of rate reduction across the five different treatment subgroups. Pearson Correlation Analysis was conducted to examine the relationship between baseline progression rate and the magnitude of reduction. A two-tailed *P*-value of <0.05 was considered statistically significant.

Table 1 Visual Training Protocol

Training Module	Clinical Objective	Typical Instrumentation & Equipment	Allocated Time
1. Static Ocular Alignment	Maintain stable fixation and binocular alignment	Brock String, Vectograms	10 minutes
2. Dynamic Ocular Alignment	Improve accurate saccadic and pursuit eye movements	Hart Charts, Sanet Vision Integrator (SVI)	10 minutes
3. Fusional Convergence	Strengthen positive fusional vergence (PFV) reserves	Aperture Rule, Base-Out Prism Flippers, Variable Tranaglyphs	10 minutes
4. Dynamic Stereopsis	Enhance depth perception judgments of moving stimuli	Computerized binocular vision therapy systems, Rotating Pegboard	10 minutes
5. Coarse (Large-range) Stereopsis	Stimulate global stereoscopic processing using large-disparity targets	Eccentric Circles, Lifesaver Cards	5 minutes

Results

Patient Demographics and Baseline Characteristics

A total of 208 subjects (208 eyes) were included in this retrospective analysis. The study cohort had a mean age of 9.73 ± 2.08 years (range: 5 to 15 years) at the commencement of visual training. The baseline mean spherical equivalent (SE) refraction of the right eye was -1.83 ± 1.61 D (range: -8.13 to $+1.75$ D), and the mean baseline axial length (AL) was 24.23 ± 0.99 mm.

The subjects were categorized into five subgroups based on their concurrent myopia control modalities: Defocus Spectacles ($n=68$, 32.7%), Orthokeratology (OK) Lenses ($n=58$, 27.9%), Visual Training Monotherapy ($n=33$, 15.9%), OK Lenses combined with Low-Concentration Atropine ($n=26$, 12.5%), and Defocus Spectacles combined with Low-Concentration Atropine ($n=23$, 11.1%). The detailed baseline characteristics are summarized in Table 2. Prior to the intervention, all included subjects exhibited binocular vision anomalies—predominantly accommodative lag and reduced positive fusional vergence—which served as the clinical indication for the visual training.

Overall Efficacy of Visual Training in Retarding Axial Elongation

A longitudinal self-controlled analysis was conducted on 208 subjects to evaluate the efficacy of visual training in controlling axial length (AL) elongation. Prior to the intervention, the cohort exhibited a rapid phase of myopia progression, characterized by a mean right eye axial elongation rate of 0.38 ± 0.34 mm/year. Following the visual training intervention, the mean axial elongation rate significantly decreased to 0.23 ± 0.30 mm/year (Figure 1A). A Wilcoxon signed-rank test demonstrated that this reduction was statistically significant ($Z = 16,935.0$, $P < 0.001$). The intervention resulted in a mean reduction in axial growth speed of 0.15 ± 0.31 mm/year (Figure 1B), effectively decelerating the pathological elongation rate to a level approaching physiological eye growth (typically 0.1–0.2 mm/year). Effect size analysis yielded a Cohen's d of approximately 0.48, indicating a moderate clinical effect. These findings provide robust evidence that visual training serves as a potent independent intervention capable of significantly altering the natural history of myopia progression.

Universality and Independence of Visual Training as an Adjunctive Therapy

To determine whether the efficacy of visual training is dependent on concurrent optical or pharmacological treatments, subjects were stratified into five subgroups based on their combined myopia control modalities (Table 3, Figure 1C): Orthokeratology (OK) lenses, Defocus Spectacles (DS), OK lenses + Atropine, DS + Atropine, and Visual Training monotherapy (None). A Kruskal–Wallis H -test revealed no statistically significant difference in the magnitude reduction

Table 2 Baseline Characteristics of the Study Population

Characteristic	All Subjects (N=208)
Age (years)	
Mean \pm SD	9.73 \pm 2.08
Range	5–15
Spherical Equivalent Refraction (D)	
Mean \pm SD	-1.83 \pm 1.61
Range	-8.13 to +1.75
Axial Length (mm)	
Mean \pm SD	24.23 \pm 0.99
Concurrent Myopia Control Modality, n (%)	
Visual Training Monotherapy (None)	33 (15.9%)
Defocus Spectacles	68 (32.7%)
Defocus Spectacles + Low-concentration Atropine	23 (11.1%)
Orthokeratology (OK) Lenses	58 (27.9%)
OK Lenses + Low-concentration Atropine	26 (12.5%)

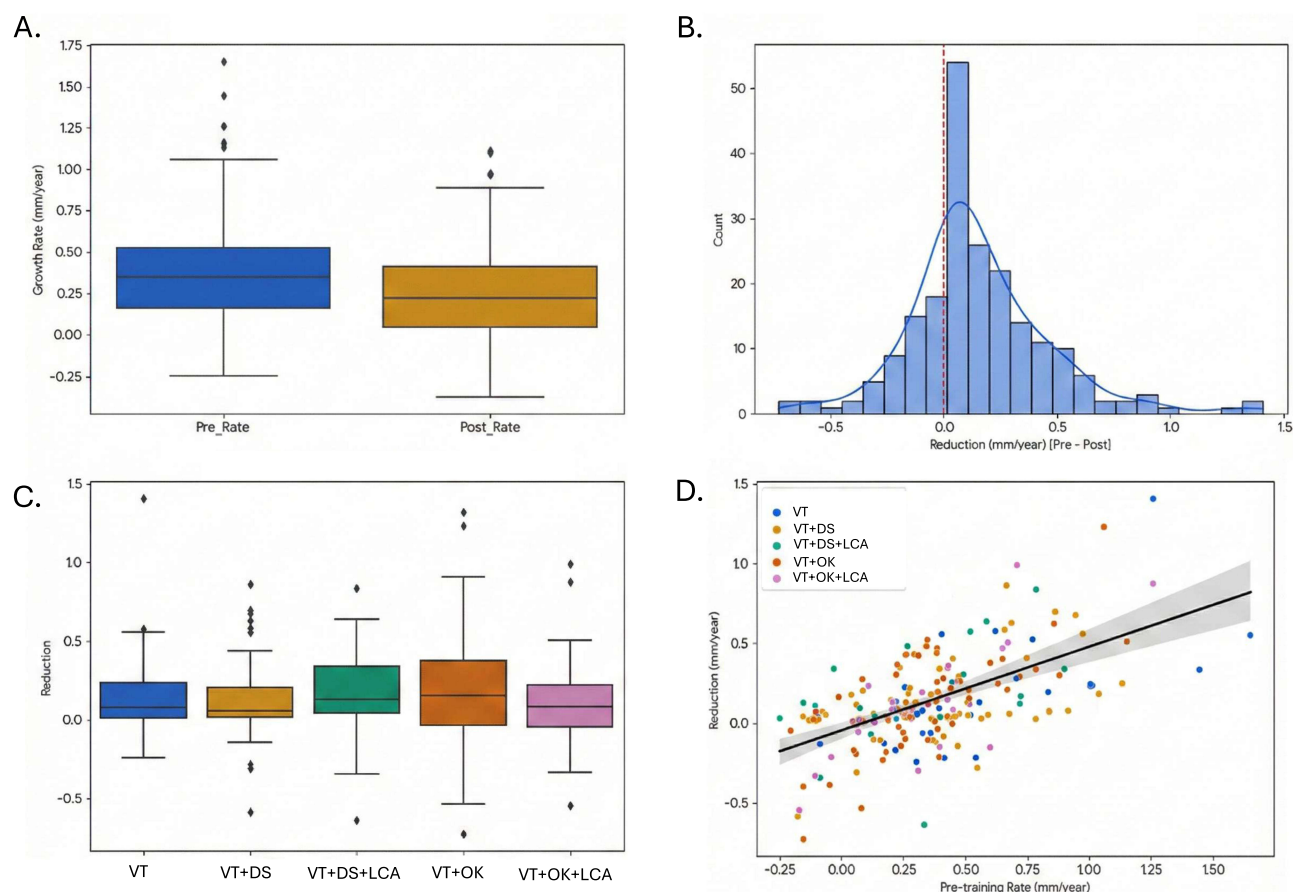


Figure 1 Efficacy of visual training on retarding axial elongation in myopic children. **(A)** Paired boxplot comparison of annualized axial elongation rates before (Pre) and after (Post) the visual training intervention. The intervention resulted in a significant reduction in the median axial growth rate. The central lines represent medians, box edges denote the interquartile range (IQR), and whiskers extend to 1.5×IQR. **(B)** Histogram showing the distribution of the reduction in axial elongation rate (defined as Pre-rate minus Post-rate). The red dashed line marks zero change; the right-skewed distribution indicates that the majority of subjects experienced a positive reduction (slowing) of axial growth. **(C)** Boxplot comparing the therapeutic effect (reduction in elongation rate) across five subgroups stratified by concurrent myopia control modalities. The Kruskal–Wallis test revealed no statistically significant differences among the groups ($P = 0.826$), suggesting a consistent additive benefit of visual training regardless of the combined therapy. **(D)** Scatter plot with a linear regression line illustrating the relationship between the baseline pre-training axial elongation rate (x-axis) and the magnitude of rate reduction (y-axis). A significant positive correlation (Pearson’s $r = 0.57$, $P < 0.001$) indicates that subjects with faster initial progression derived greater therapeutic benefit from visual training. **Abbreviations:** VT, visual training; DS, Defocus Spectacles; LCA, Low-concentration Atropine; OK, Orthokeratology.

of AL rate among the groups ($P = 0.826$). Specifically, subjects receiving visual training monotherapy achieved a mean reduction of 0.16 mm/year, which was highly comparable to the reductions observed in the OK lens group (0.18 mm/year) and the DS + Atropine group (0.18 mm/year). This lack of significant inter-group difference underscores the

Table 3 Subgroup Analysis of Axial Growth Reduction by Combined Treatment Method

Group (Combined Method)	N	Mean Reduction (mm/yr)	95% CI
Visual Training Only (None)	33	0.16 ± 0.32	[0.05, 0.27]
Defocus Glasses	68	0.13 ± 0.24	[0.07, 0.19]
Defocus Glasses + Atropine	23	0.18 ± 0.31	[0.05, 0.31]
OK Lens	58	0.18 ± 0.37	[0.08, 0.28]
OK Lens + Atropine	26	0.11 ± 0.34	[-0.03, 0.25]

Note: No statistically significant differences were observed among the subgroups ($P > 0.05$). **Abbreviation:** CI, Confidence Interval.

“additive effect” of visual training. Regardless of whether a patient is currently managing myopia with orthokeratology or low-concentration atropine, the addition of visual training provides a consistent and independent benefit of approximately 0.15 mm/year. This suggests that visual training has broad clinical indications and can be effectively integrated as a universal adjunctive therapy into existing myopia management protocols.

Identification of Optimal Candidates and Precision Intervention Strategies Based on Baseline Progression

Correlation analysis between baseline axial elongation rates and the magnitude of post-training reduction was performed to identify the population that benefits most from this intervention (Figure 1D). Pearson correlation analysis indicated a significant positive correlation ($r = 0.57$, $P < 0.001$), suggesting that children whose eyes were elongating at a faster rate (mm/year) prior to the intervention experienced the larger drop in their growth rate after the intervention. Scatter plot analysis further elucidated that for “rapid progressors”—children exhibiting explosive axial growth (eg., >0.5 mm/year) despite conventional control measures—visual training exerted a dramatic inhibitory effect, substantially curtailing the rate of elongation. Conversely, while children with slower baseline growth also benefited, the magnitude of reduction was more moderate. These findings provide a critical basis for clinical decision-making: for refractory cases where myopia continues to progress rapidly despite standard treatments, visual training should be prioritized as a “rescue therapy.” Its significant “peak-shaving” effect on axial growth velocity is crucial for preventing the transition of these high-risk individuals into high myopia.

Discussion

The present study provides compelling retrospective evidence regarding the efficacy of visual training (VT) as a potent intervention for myopia control. Our findings demonstrate that a structured VT program significantly reduced the mean annualized axial elongation rate from a rapid, pathological trajectory (0.38 mm/year) to a level approaching physiological emmetropic growth (0.23 mm/year). This reduction of approximately 0.15 mm/year is clinically meaningful, comparable to the treatment effects reported for 0.01% low-concentration atropine or defocus-incorporated spectacles in recent landmark trials. To our knowledge, this is one of the first studies to quantify the “additive” efficacy of visual training across a spectrum of concurrent myopia control modalities based on axial length—the gold standard metric for progression.

The mechanism by which visual training retards axial elongation is likely multifactorial, centering on the amelioration of binocular vision anomalies that drive myopigenesis. High accommodative lag and unstable accommodation have been implicated in producing hyperopic retinal defocus, a potent stimulus for axial growth.^{14–18} Furthermore, vergence dysfunction can induce transient visual blur and visual fatigue.^{19–21} We postulate that the VT protocol employed in this study, which emphasized improving accommodative facility and fusion reserves, effectively reduced accommodative lag and stabilized retinal image quality. By refining the oculomotor control system, VT may minimize the cumulative duration of retinal blur during near work, thereby downregulating the scleral signaling pathways responsible for elongation.

A pivotal finding of this study is the uniformity of therapeutic benefit across diverse subgroups. We observed no statistically significant difference in the magnitude of axial slowing between children using VT alone, VT with orthokeratology, or VT with atropine. This suggests that the therapeutic pathway of visual training is distinct from and complementary to optical and pharmacological mechanisms. While orthokeratology and defocus spectacles operate primarily by imposing peripheral myopic defocus,^{22,23} and atropine acts via muscarinic receptor pathways,^{24–26} visual training targets the neuromuscular and sensory processing aspects of vision.¹² Consequently, VT acts as a universal “booster”, providing an additive effect regardless of the primary control modality. This finding supports the integration of VT as a standard adjunctive therapy in multimodal myopia management protocols.

Our correlation analysis revealed a good positive relationship between baseline progression rate and the magnitude of treatment effect. Children with the most rapid initial axial growth experienced the most dramatic deceleration. While this observation may partially reflect the statistical phenomenon of regression to the mean, the magnitude of the effect suggests a genuine biological response.²⁷ Clinically, this identifies a clear target demographic, the non-responders to

standard care. For children whose myopia continues to spiral despite optimal optical or pharmacological intervention, visual training may serve as a critical rescue therapy to brake the acceleration phase of axial elongation.

Several limitations of this study warrant consideration. First, the retrospective nature and the absence of a concurrent control group receiving no intervention (or a “sham” training group) limit our ability to strictly infer causality, although the self-controlled design mitigates inter-subject variability. Second, the follow-up duration was variable; while annualized rates were used for standardization, longer-term studies are needed to assess the sustainability of the training effect after cessation. Furthermore, detailed binocular function parameters (eg., AC/A ratio changes) were not analyzed in this specific report, which limits our ability to directly correlate functional improvements with structural changes. Finally, near-work duration and exposure to visual display units (VDUs) were not systematically quantified, which could introduce confounding variables.

Conclusion

In conclusion, visual training serves as an effective, safe, and universally applicable strategy for slowing axial elongation in myopic children. It offers a significant additive benefit when combined with existing treatments like orthokeratology and atropine, and demonstrates particular efficacy in children with rapid baseline progression. These findings advocate for a paradigm shift in myopia management—moving from a purely optical/pharmacological approach to a holistic model that includes functional visual rehabilitation.

Data Accessibility

Data associated with this paper can be requested from the corresponding author.

Ethics Guidelines

Ethical clearance was obtained from the Beijing New Vision Eye Hospital’s Ethics Committee and Institutional Review Board (IRB) (approval no. 2025005).

Consent to Publish

All authors confirm their consent for the publication of this work.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

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