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Original Article

Visual training system 4: a promising adjuvant therapy for ocular accommodative function and visual acuity improvement in refractive amblyopia patients

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Abstract: Objective: To evaluate the therapeutic effects of Visual Training System 4 (VTS4) as an adjunctive therapy for patients with refractive amblyopia. Method: A total of 82 patients with refractive amblyopia (142 eyes) treated at the Zhongshan Ophthalmic Center of Sun Yat-sen University, were enrolled and divided into two groups based on the treatment protocol. The control group included 40 patients (68 eyes) who received conventional comprehensive treatment, while the observation group was comprised of 42 patients (74 eyes) treated with VTS4 in addition to conventional therapy. The therapeutic effects, best-corrected visual acuity (BCVA), spherical equivalent (SE), ocular accommodative function, and ocular convergence were compared between the two groups. Results: The total effective rate of visual improvement in the observation group was 86.49%, significantly higher than 66.18% in the control group. BCVA at 3 and 6 months was superior in the observation group compared to the control group ($P < 0.05$). At 6 months, the normal rate of binocular fusion images in the observation group was 94.59%, higher than 76.47% in the control group. The observation group showed greater improvement in accommodative flexibility and amplitude, and lower accommodative lag compared to the control group. Improvements in negative relative accommodation, positive relative accommodation, and near point of convergence were also more pronounced in the observation group (all $P < 0.05$). No significant differences were observed in SE, axial length, or corneal curvature within or between the groups before and after treatment (all $P > 0.05$). Conclusion: VTS4, as an adjunctive therapy for refractive amblyopia, significantly improves visual acuity, enhances accommodative and convergence functions, and demonstrates strong clinical applicability.

Keywords: Visual training system 4, refractive error, amblyopia

Introduction

Amblyopia is a condition in which pediatric patients exhibit reduced best-corrected visual acuity (BCVA) in one or both eyes compared to the normal visual acuity expected during the visual development stage, despite the absence of organic ocular pathology [1]. Amblyopia is a complex visual disorder with significant implications for a child's visual perception and overall development. It not only results in reduced visual acuity but also interferes with a child's ability to perceive and interact effectively with their surroundings. As it often remains undetected until it impacts daily activities and learning, amblyopia poses a unique clinical challenge. It is a leading cause of visual acuity impairment in children, affecting the intricate development of visual function.

The condition can limit a child's ability to participate in activities such as reading, writing, and sports, thereby hindering educational progress and overall quality of life. The global prevalence of amblyopia is approximately 4.3%, exerting a notable impact on children's mental health and well-being [2]. Among the various types, refractive amblyopia is a predominant form, charac-

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terized by bilateral retinal imaging blur, which often leads to binocular amblyopia due to the symmetrical degree of blurriness in both eyes [3].

Clinical treatment typically involves refractive correction and occlusion of the dominant eye. While these methods can improve visual acuity, they require prolonged treatment, and low compliance among some patients can result in suboptimal recovery outcomes [4]. Thus, there is a growing need for more effective treatment modalities [5, 6].

Visual Training System 4 (VTS4) is an innovative visual training tool that combines interactivity and immersion. It coordinates visual, tactile, and auditory inputs to enhance neural function repair, facilitating binocular vision reconstruction and improving visual acuity [7-10]. However, the clinical efficacy of VTS4 therapy in restoring visual acuity in patients with refractive amblyopia remains underexplored [7, 11, 12].

This study aims to analyze the effects of VTS4 therapy on ocular accommodation function and visual acuity in refractive amblyopia patients. Refractive amblyopia significantly affects children's visual development and quality of life. By investigating the efficacy of VTS4 therapy, this study seeks to provide evidence for improving visual acuity and advancing treatment options. Such findings could reduce the burden of amblyopia on individuals and society, leading to better clinical outcomes and enhanced quality of life for affected children.

Materials and methods

Case selection

This retrospective study included 82 patients (142 eyes) diagnosed with refractive amblyopia who attended the Zhongshan Ophthalmic Center, Sun Yat-sen University from January 2021 to April 2023. This study was approved by the Ethics Committee of Zhongshan Ophthalmic Center. Patients were divided into two groups based on their treatment plans: the control group included 40 patients (68 eyes), and the observation group included 42 patients (74 eyes).

Inclusion criteria: (1) Patients meeting the diagnostic criteria for amblyopia [6]. (2) Refractive error confirmed by dilated pupil optometry. (3) No prior systematic treatment for amblyopia. (4) Good compliance, enabling cooperation with ophthalmologic examinations and amblyopia training. (5) Complete treatment data.

Exclusion criteria: (1) Patients with organic ocular pathology. (2) History of ophthalmic surgery. (3) Presence of nystagmus or congenital ocular developmental anomalies. (4) Non-refractive amblyopia. (5) Mental or growth retardation. (6) Incomplete patient information.

Intervening methods

The control group received refractive correction, a conventional comprehensive treatment. Refraction was performed following pupil dilation and optometry. Refraction was reassessed every three months, and spectacle prescriptions were adjusted accordingly. Routine occlusion therapy was adopted. Appropriate eye patch sizes were selected based on binocular visual conditions. For patients with ≤ 2 lines of interocular visual acuity difference, alternating occlusion was applied; for those with > 2 lines of difference, the better-seeing eye was occluded first, followed by the worse-seeing eye. Occlusion duration was adjusted based on severity: Mild-to-moderate amblyopia: 2-4 hours/day. Severe amblyopia: 4-6 hours/day. Once visual acuity reached ≥ 0.9, occlusion was reduced to 1 hour/day. Visual function correction was employed. Patients performed fine motor exercises, such as tracing, threading needles, stringing beads, and light brushing, at home. Patients underwent regular follow-ups at the hospital outpatient clinic, with training and review results recorded over six consecutive months.

The observation group underwent VTS4 adjuvant therapy in addition to the comprehensive treatment protocol described for the control group. The VTS4 training system, developed by HTS Inc. (USA), was used. A diagnostic module evaluated patient-specific parameters, including occult obliquity, scanning, rotational occult obliquity, binocular disparity, and visual memory. Based on the diagnostic results, patients underwent targeted training: Monocular augmentation. Monocular fine manipulation within a binocular field of view. Binocular manipulation training. Training was conducted one-on-one by the same physician for consistency.

Sessions were held three times a week for six months.

Data collection and observation indicators

The main indicators included treatment effect and BCVA, while secondary indicators comprised equivalent spherical lens (SE), ocular adjustment function, ocular convergence, axial length, and corneal curvature.

Treatment effect: The treatment outcome was evaluated comprehensively after 6 months [8]: Basically cured: Visual acuity in the affected eye improved to ≥ 0.9. Effective: Visual acuity improved by ≥ 2 lines compared to pre-treatment. Ineffective: No change, regression, or improvement by only 1 line.

BCVA: BCVA was measured using the international standardized visual acuity scale before treatment, and at 3 and 6 months post-treatment. Results were converted to LogMAR for analysis. Only the eye with poorer visual acuity was selected. If both eyes had the same BCVA, the right eye was used for testing.

Equivalent SE: Optometry was performed at the same time points, recording the spherical lens power, cylindrical lens power, and axial position. SE was calculated as the spherical lens power + 1/2 of the cylindrical lens power. Normal fusion function: Four dots visible at different locations. Abnormal fusion: Three or two dots visible, indicating suppression of the right or left eye; alternate suppression occurred if dots were indeterminate.

Ocular adjustment function: Before and 6 months after treatment, comprehensive optometry was used to measure: Adjustment flexibility via positive and negative spherical lens flip tests. Adjustment amplitude via negative lens tests. Adjustment lag via fusion cross-cylinder lens tests.

Ocular convergence: Stereopsis at 40 cm was used to measure negative relative accommodation (NRA), positive relative accommodation (PRA), and binocular convergence proximity point (NPC) before and after treatment.

Axial length and corneal curvature: Optical biometric instruments were used to measure the ocular axis (AL), flat and steep corneal curvatures (K1, K2), and calculate mean corneal curvature (Km) as (K1 + K2) × 0.5 before treatment and at 6 months.

Statistical methods

Data analysis was performed using SPSS 26.0 statistical software. Measurement data following a normal distribution were expressed as mean ± SD and analyzed using independent t-tests, paired t-tests, or two-way ANOVA followed by Tukey's post-hoc test. Data not following a normal distribution were described using median and interquartile ranges and analyzed with rank-sum tests. Categorical data were expressed as percentages (%) and analyzed using Chi-square tests. A significance level of $P < 0.05$ was considered statistically significant.

Results

Comparison of basic information

The clinical data (sex, age, amblyopia degree, etc.) of the two patient groups were comparable (all $P > 0.05$), indicating no significant baseline differences (**Table 1**).

Comparison of therapeutic effects

At the end of treatment, the visual acuity of the observation group was significantly higher than that of the control group ($P < 0.05$), as shown in **Table 2**.

Comparison of BCVA

There was no significant difference in BCVA between the groups before treatment ($P > 0.05$). Post-treatment, BCVA improved in both groups, with the observation group showing significantly better outcomes than the control group ($P < 0.05$, **Table 3**).

Comparison of SE

No significant differences in SE were observed between the groups before treatment ($P > 0.05$). After treatment, SE remained unchanged compared to baseline in both groups, with no significant difference between the two groups post-treatment ($P > 0.05$, **Table 4**).

Comparison of binocular fusion

Before treatment, there were no significant differences in binocular fusion between the

Table 1. Comparison of baseline data between the two groups

Item	Control Group (40)	Observation Group (42)	t/χ^2	P
Number of Eyes	68	74	/	/
Gender				
Male	22	20	0.924	1.792
Female	18	22		
Age (years)	7.92±2.18	8.04±2.36	0.821	1.014
Amblyopia Degree			0.562	0.197
Mild	22	24		
Moderate	40	40		
Severe	6	10		
Refractive Error Type			1.245	0.091
Hyperopia	20	25		
Myopia	8	10		
Hyperopic astigmatism	23	24		
Myopic astigmatism	17	15		

Table 2. Comparison of treatment effects between the two groups

Group	Eyes	Basically cured	Effective	Not valid	Total effectiveness rate
Observation	74	30 (40.54)	34 (45.95)	10 (13.51)	64 (86.49)
Control	68	18 (26.47)	27 (39.71)	23 (33.82)	45 (66.18)
χ^2					8.194
P					0.004

Table 3. Comparison of BCVA between the two groups (LogMAR)

Group	Number of Eyes	Before Treatment	3 Months After Treatment	6 Months After Treatment
Observation Group	74	0.52±0.10	0.31±0.08*	0.14±0.07*
Control Group	68	0.50±0.09	0.40±0.09*	0.21±0.08*
t		1.249	6.308	5.560
P		0.214	< 0.001	< 0.001

Note: Compared with before treatment, *P < 0.05. BCVA: Best-corrected visual acuity.

Table 4. Comparison of SE between the two groups (D)

Group	Number of Eyes	Before Treatment	3 Months after Treatment	6 Months after Treatment
Observation Group	74	6.10±1.18	6.07±1.15	5.97±1.24
Control Group	68	6.06±1.20	6.02±1.12	6.00±1.20
t-value		0.200	0.262	0.146
P-value		0.842	0.794	0.884

Note: SE: Equivalent Spherical Lens Degree.

groups (P > 0.05). After treatment, the normal rate of binocular fusion increased in both groups, with the observation group showing a significantly higher normal rate at 6 months (P < 0.05, **Table 5**).

Comparison of ocular adjustment

Before treatment, there were no significant differences in binocular fusion between the groups (P > 0.05). After treatment, the normal rate of binocular fusion increased in both groups, with the observation group showing a significantly higher normal rate at 6 months (P < 0.05, **Table 6**).

Comparison of eye collection power

No significant differences were found in ocular convergence power between the groups before treatment (P > 0.05). After treatment, improvements were observed in both groups, with the observation group achieving significantly higher ocular convergence power than the control group (P < 0.05, **Table 7**).

Comparison of axial length and corneal curvature

Before treatment, no significant differences in AL or Km were observed between the groups (both P > 0.05). Post-treatment, there were no significant changes in AL or Km within or between the groups (both P > 0.05, **Table 8**).

Discussion

Amblyopia is a major neurodevelopmental abnormality affecting children's visual development, characterized by reduced visual acuity and often accompanied by impaired visual function [13-15]. Refractive error ambly-

Table 5. Comparison of Binocular fusion between the two groups

Group	Number of Eyes	Before Treatment		3 Months after Treatment		6 Months after Treatment	
		Normal	Abnormal	Normal	Abnormal	Normal	Abnormal
Observation Group	74	35 (47.30)	39 (52.70)	48 (64.86)	26 (35.14)	70 (94.59)*	4 (5.41)
Control Group	68	30 (44.12)	38 (55.88)	39 (57.35)	29 (42.65)	52 (76.47)*	16 (23.53)
χ^2		0.144		0.843		9.619	
P		0.704		0.359		0.002	

Note: Compared with before treatment, *P < 0.05.

Table 6. Comparison of Ocular Adjustment between the two groups

Group	Number of Eyes	Accommodation Amplitude (D)		Accommodation Sensitivity (cpm)		Accommodation Lag (D)	
		Before	After	Before	After	Before	After
Observation Group	74	12.38±1.24	15.13±1.02*	5.78±0.84	9.15±1.28*	1.50±0.48	0.42±0.12*
Control Group	68	12.41±1.28	14.01±0.92*	5.81±0.85	7.28±1.34*	1.47±0.51	0.78±0.29*
t		0.142	6.849	0.211	8.504	0.361	9.806
P		0.887	< 0.001	0.833	< 0.001	0.719	< 0.001

Note: Compared with before treatment, *P < 0.05.

Table 7. Comparison of Eye collection power between the two groups

Group	Number of Eyes	NRA (D)		PRA (D)		NPC (cm)	
		Before	After	Before	After	Before	After
Observation Group	74	1.10±0.41	2.48±0.21*	-0.75±0.28	-2.48±0.48*	20.19±5.68	7.18±1.25*
Control Group	68	1.08±0.43	2.01±0.20*	-0.73±0.26	-1.76±0.50*	19.87±5.71	8.96±1.36*
t		0.284	13.630	0.440	8.753	0.335	8.127
P		0.777	< 0.001	0.661	< 0.001	0.738	< 0.001

Note: NRA: Negative relative accommodation, PRA: Positive relative accommodation, NPC: binocular convergence proximity point. Compared with before treatment, *P < 0.05.

Table 8. Comparison of Eye Axis, Corneal Curvature between the two groups

Group	Number of Eyes	AL (mm)		Km (D)	
		Before	After	Before	After
Observation Group	74	19.82±1.28	20.10±1.36	41.82±3.46	42.08±3.61
Control Group	68	20.04±1.26	20.34±1.42	42.04±3.52	42.58±3.71
t		1.031	1.029	0.375	0.814
P		0.304	0.305	0.708	0.417

Note: AL: Ocular axis, Km: corneal curvature.

opia arises from refractive issues that prevent light from properly focusing on the macular center of the retina, resulting in insufficient stimulation of the central nervous system [16-19]. Conventional treatments, such as corrective lenses and dominant eye occlusion, aim to facilitate accurate visual signal processing and visual system development [20-22]. However, these methods are time-consuming, slow, and demand high patient compliance [23].

VTS4 is an innovative visual training tool for amblyopia treatment that stimulates visual acuity and fine resolution. Through interactive modules, including games and 3D videos, it provides advanced binocular vision and visual

perception training [7]. Compared to traditional methods, VTS4 has the potential to improve visual acuity more efficiently and within a shorter timeframe [24-27]. This novel approach offers a promising alternative for treating refractive error amblyopia. This study demonstrated that the total effective rate of visual acuity improvement in the observation group at the end of treatment was 86.49%, significantly higher than the 66.18% observed in the control group. Additionally, BCVA at 3 and 6 months of treatment was better in the observation group than in the control group, indicating that VTS4 adjunctive therapy effectively enhances patients' visual acuity. Kwarteng MA and colleagues [28-30] reported that using a visual training system as an adjunctive method to masking therapy significantly improves the visual acuity of amblyopic eyes and addresses the issues of compliance or limited efficacy with masking therapy alone. Similarly, Molina-Martín and colleagues [14] highlighted that virtual reality-based perceptual learning systems can enhance stereoscopic vision in amblyopia patients, making them an ideal adjunctive therapy.

The underlying mechanism of VTS4 therapy lies in its ability to achieve multidimensional interaction through auditory, visual, and tactile stimulation. This approach maximizes patients' visual ability and attention, alleviates visual inhibition caused by amblyopia, activates the affected eye's visual focus ability, and improves visual acuity. Furthermore, continuous and repetitive visual stimulation enhances the activity of visual neural networks, increases the sensitivity of central optic nerve cells and retinal visual cells, and promotes the recovery of optic neurons. These effects collectively improve visual acuity and highlight VTS4's potential as an effective adjunctive therapy for amblyopia [31].

Binocular fusion refers to the ability of both eyes to merge visual input into a single image and maintain this perception when focusing on objects at varying distances. Patients with refractive amblyopia often experience abnormal binocular fusion due to refractive errors, leading to visual dysfunction and impaired stereopsis [32]. Benhaim-Sitbon et al [16] reported that binocular fusion disorders are common in amblyopic patients and contribute to developmental disorders of binocular vision.

This study found that the normalization rate of binocular fusion in the observation group at 6 months was 94.59%, significantly higher than the 76.47% observed in the control group. This suggests that VTS4 therapy promotes binocular development and improves binocular fusion function. Fine eye training within VTS4 therapy enhances visual acuity and employs binocular vision training with variable contrast images presented to each eye. By real-time adjustment of binocular contrast, the system achieves balanced visual input from both eyes, improves binocular coordination, and stimulates neuronal pathways for smooth signal transmission. This process enhances binocular fusion function and contributes to overall visual development. That is to say, VTS4 therapy effectively improves binocular fusion function, promotes visual acuity, and supports overall visual development, offering significant potential for treating refractive amblyopia.

Ocular accommodation is fundamental to maintaining normal visual function [33]. Hong et al [17] reported that 45.10% of patients experienced significant visual acuity improvement after 10.5 months of refractive correction and masking therapy. This study found that after treatment, the observation group exhibited greater flexibility and amplitude of accommodation, lower accommodation lag, and higher improvements in NRA, PRA, and binocular NPC compared to the control group. These findings suggest that VTS4 therapy can effectively enhance ocular accommodation and convergence functions. Michalski et al [18] emphasized that visual training systems can reduce ocular inhibition, enhance brain neuroplasticity, and improve patients' visual function. Lan et al [22] noted that amblyopic children retain some degree of visual plasticity, and visual perception learning systems can enhance binocular visual experience, improve dynamic stereoscopic visual function, and promote ocular regulation and convergence abilities.

The mechanism of VTS4 therapy lies in its use of precise optical stimulation, such as fine visual tasks and red light stimulation, to enhance signal reception by the visual cortex, promote central nervous system development, and improve visual acuity. Additionally, adjustment and fusion training increase the amplitude and flexibility of ocular accommodation, further enhancing visual function. Binocular split-vision

and visual perception training balance binocular visual input, improve binocular coordination, and enhance convergence ability. Functional training, including exercises for fine vision, fusion, movement, balance, and coordination, improves stereoscopic vision and visual cortex plasticity, ultimately enhancing ocular accommodation and convergence functions. These results suggest that VTS4 therapy is a promising method to improve eye regulation and convergence, thus enhancing patients' visual health and quality of life.

VTS4 therapy integrates multimedia tools with games and training tasks to increase patient engagement, concentration, and therapeutic motivation. However, concerns about potential harm from electronic screens, such as myopic drift, remain. This study found no significant differences in SE, axial length, or corneal curvature between the two groups before, during, and after treatment, indicating that VTS4 therapy did not increase the risk of myopic drift. However, the limited observation period of 6 months and the treatment schedule of three sessions per week, rather than continuous therapy, may have minimized potential side effects. Therefore, further studies are needed to comprehensively evaluate the long-term effects and specific risks associated with VTS4 therapy. This study does have a few limitations, including a small sample size and retrospective design, which may introduce selection bias. Future research should include larger sample sizes, randomized controlled trials, and extended observation periods to provide more robust and accurate data for amblyopia treatment. In conclusion, VTS4 therapy as an adjunctive treatment improves visual acuity, enhances ocular accommodation and convergence functions, promotes binocular fusion, and aids in reconstructing stereoscopic vision without increasing the risk of myopic drift. These findings support its clinical application.

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Disclosure of conflict of interest

None.

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