• Clinical Research •

Positive/negative binocular fusional C-optotypes and 2D planar C-optotypes on transient accommodation and stability in adult eyes: implications for myopia prevention and control

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Abstract

● **AIM:** To investigate the effects of binocular fusional C-optotypes (positive/negative) and 2D planar C-optotypes on the amplitude and stability of transient accommodation (TAC) in adults, and to provide a basis for non-contact myopia intervention.

● **METHODS:** This was a self-controlled study. Using red-blue 3D technology, four experimental stages were set up: Test A [fixating on the 1 m negative fusional C-optotypes, 8△ base-in (BI)], Test B (fixating on the 5 m planar C-optotypes), Test C (fixating on the 1 m planar C-optotypes), and Test D [fixating on the 1 m positive fusional C-optotypes, 20△ base-out (BO)]. A WAM-5500 open-field autorefractor was used to measure TAC and accommodative microfluctuations [evaluated *via* interquartile range (IQR) and median-based coefficient of variation (CV_{med})]. Additionally, the convergence accommodation to convergence (CA/C) ratio was calculated, and a visual fatigue questionnaire was administered to assess participants' subjective visual comfort.

● **RESULTS:** A total of 21 subjects (7 males, 14 females; aged 23-41y) with normal binocular visual function were enrolled. The results showed that the TAC increased gradually across the four stages, and these values were Test A (-0.35±0.26 D)<Test B (-0.46±0.24 D)<Test C (-0.77±0.32 D)<Test D (-1.38±0.31 D). There were significant overall differences (F=56.136, P<0.001). Compared with Test C, Test A reduced TAC by 0.42 D (P<0.05), while Test D increased it by 0.61 D (P<0.001). There was no significant intergroup difference in accommodative fluctuation amplitude (all P>0.05), but the fluctuation stability of Test D showed a significant difference between the first 20s and the second 20s (P=0.017). The CA/C ratio was significantly higher in Test D (0.05±0.02 D/△) than in Test A (0.03±0.02 D/△, P=0.007), indicating stronger accommodation-convergence linkage during positive fusional fixation. The visual fatigue scores of all stages were low (median 0-1), with Test D slightly higher than Test B and Test C (P<0.05). No linear correlation was found between TAC and age (all r<0.1, P>0.05).

● **CONCLUSION:** Negative fusional C-optotypes induce ciliary muscle relaxation to reduce TAC, while positive fusional C-optotypes enhance accommodation-convergence coordination to increase TAC. The red-blue 3D-based non-contact training mode exhibits good safety (median visual fatigue scores: 0-1 across all tests) and provides a novel dual-directional (relaxation-activation) strategy for myopia prevention and control.

● **KEYWORDS:** fusional accommodation; transient accommodation; accommodative stability; myopia control
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INTRODUCTION

Myopia has become a major global public health issue, with its prevalence continuing to rise across all age groups, and it poses a serious threat especially to the visual health of adolescents[1-3]. It is predicted that the global prevalence of myopia will reach 39.8% by 2050[4], while the prevalence of myopia in the 15-19y age group in China has reached as high as 67.2%[5]. The occurrence of myopia is closely related to genetic and environmental factors, among which ciliary muscle dysfunction is a key pathogenic link[6-9]. Prolonged near work induces ciliary muscle spasm, which

subsequently leads to lens accommodation lag and aberrant ocular blood flow; these pathological changes collectively drive abnormal axial elongation, representing the core underlying cause of the challenges in effective myopia control. Currently, clinical approaches such as atropine, contact lenses, and flipper visual function training can improve ciliary muscle function and exert a certain effect on myopia prevention and control[1,10-11], but all have obvious application limitations. For example, the adverse reactions of atropine[12]; the unstable efficacy and potential complications of orthokeratology lenses due to individual differences[10,13]; and flipper training relies on specialized hardware equipment, which not only increases the cost of clinical application but also is restricted by site and portability, making widespread application difficult.

Given that the binocular fusional process directly regulates accommodation function *via* the fusional accommodation mechanism[14], breaking through the limitations of existing studies to clarify the quantitative indicators of fusional training's impact on transient accommodation (TAC) would enable the development of a non-contact software-based fusional training program. This program can not only avoid the safety risks and application limitations of traditional methods but also lower the threshold for clinical promotion, providing a safer, more convenient, and accessible new path for myopia prevention and control.

However, existing studies have critical gaps: Simmons and Firth[14] only compared CA/C ratios between base-in (BI) and base-out (BO) fusion induced by prisms, without quantifying dynamic changes in TAC; Nonaka *et al*[15] linked low CA/C to reduced tonic accommodation but ignored the differential effects of positive/negative fusional targets. Neither of the two studies addressed the lack of non-contact, software-based fusional training protocols—an unmet need for myopia control. To fill this gap, we quantified TAC and stability under planar (different distances) and positive/negative fusional C-optotypes using red-blue 3D technology.

PARTICIPANTS AND METHODS

Ethical Approval This study was approved by the Ethics Committee of He Eye Specialist Hospital [approval number: IRB (2023) K033.01]. Before the study, researchers fully informed each subject of the study-related information, and written informed consent was obtained after the subjects fully understood the study. During the study, the ethical principles of the Declaration of Helsinki were strictly followed to protect the subjects' right to information and voluntary participation. Meanwhile, the subjects' privacy was fully protected through standardized information management procedures.

Study Participants A total of 21 subjects (7 males, 14 females; aged 23-41y) with normal binocular visual function were enrolled. Due to high interocular correlation of accommodative indicators, the right eye was selected as the study eyes for all subjects to reduce measurement bias.

Inclusion criteria: no gender restriction, age≥18y; best-corrected visual acuity (BCVA) ≤0.0 logMAR (logarithm of the minimum angle of resolution), measured at 5 m; normal eye position, fusional function, accommodation function and stereoscopic acuity (assessed *via* phoropter and Titmus stereogram).

Exclusion criteria: a history of eye surgery, trauma, or treatment for active eye diseases within the past 3mo; moderate to severe dry eye or other active ocular surface diseases; current use of drugs affecting vision (*e.g.*, olanzapine, loratadine, atropine); uncontrolled systemic diseases such as diabetes and hypertension; communication disorders.

Study Type This was a self-controlled study (pre-post design).

Instruments and Equipment The Beishiyou Visual Function Training Software (Version 2.0; Shenyang Beiyou Technology, China) was used, and its binocular fusional training function module was selected. Based on red-blue dichoptic technology, this software can generate positive/negative fusional C-optotypes and planar C-optotypes, with the target visual angle uniformly set to 1' (conforming to the adult visual resolution threshold). The positive fusional C-optotypes refer to 2D targets with crossed parallax, delivered dichoptically to each eye *via* red-blue dichoptic glasses, and after fusion by the brain, the perceived distance of the target is closer than the original physical distance; the negative fusional C-optotypes refer to 2D targets with uncrossed parallax, presented dichoptically through red-blue dichoptic glasses, where the brain's fusion results in a perceived distance further than the original physical distance; and the planar C-optotypes refer to 2D planar targets without any dichoptic design.

The software includes a built-in timing module and fixation guidance prompt (instructing subjects to fuse binocular images into a single clear target), ensuring stable completion of the fixation task.

During the experiment, the subjects were equipped with red-blue dichoptic glasses (to achieve binocular dichoptic viewing and avoid the interference of binocular visual signal superposition) and a 24-inch liquid crystal display (resolution: 1920×1080, refresh rate: 60 Hz, used for displaying C-optotypes). The brightness of the display was calibrated to 300 nits, and the ambient light intensity was adjusted to 400 lx. These parameters were matched to reduce the interference of non-experimental factors.

In the experiment, a WAM-5500 open-field autorefractor (Grand Seiko Co. Ltd., Japan) was used to measure the TAC of the subjects' eyes. This device is equipped with an automatic tracking system, which can collect and record indicators such as pupil diameter and TAC in real time, with a measurement

accuracy of ±0.01 D. Its measurement principle is to measure refractive status by projecting an infrared annular pattern onto the retina and analyzing the deviation of the reflected pattern on the corneal surface; after the subjects' eyes are accurately focused, the refractive status data of the eyes are analyzed and output in real time[16-19].

Experimental Procedures 1) Recruitment and enrollment of subjects, followed by obtaining informed consent; 2) baseline examination: including ocular parameters (BCVA, eye position, fusional function, accommodation function, and Titmus); 3) conducting Test A, Test B, Test C, and Test D in sequence; 4) end of the experiment. The process is shown in Figure 1.

Subjects were seated in front of a WAM-5500 open-field autorefractor, wearing both their refractive correction glasses and red-blue dichoptic glasses. They viewed visual optotypes directly ahead through the transparent window at the front of the device and completed four experimental phases sequentially: Test A (1-meter negative fusional C-optotypes, 8△ BI, 40s fixation), where under software control, two identical red-blue C-optotypes initially overlapped before symmetric horizontal separation. Through the right eye's blue filter, only the red C-optotypes (moving rightward) were visible; through the left eye's red filter, only the blue C-optotypes (moving leftward) were detectable. Binocular fusion formed a 3D virtual C-optotypes (positioned directly ahead of the subject and recessed relative to the screen plane), and movement ceased at 8△ BI. Subjects then maintained fixation on the virtual C-optotypes' opening for 40s, with real-time instantaneous accommodative power recorded using the WAM-5500. Test B (5-meter planar C-optotypes, 40s fixation) involved subjects fixating on the opening of the 5-meter planar C-optotypes for 40s, with real-time accommodative power recorded using the WAM-5500 throughout. Test C (1-meter planar C-optotypes, 40s fixation) was identical to Test B except for the 1-meter target distance, with the same fixation duration and accommodative power recording protocol. Test D (1-meter positive fusional C-optotypes, 20△ BO, 40s fixation), where two overlapping red-blue C-optotypes underwent symmetric horizontal separation under software control. Through the right eye's blue filter, only the red C-optotypes (moving leftward) were visible; through the left eye's red filter, only the blue C-optotypes (moving rightward) were detectable. Binocular fusion generated a 3D virtual C-optotypes (positioned directly ahead of the subject and protruding from the screen plane), and movement halted at 20△ BO. Subjects sustained fixation on the virtual C-optotypes' opening for 40s, with real-time accommodative power recorded using the WAM-5500.

Immediately after each experimental stage, a visual fatigue questionnaire was used to evaluate the subjects' subjective comfort. To avoid the impact of visual fatigue on the results, the subjects were required to look far away and rest for 5min after each experimental stage. In this study, both 1 and 5 m referred to the distance between the human eye and the fixation target.

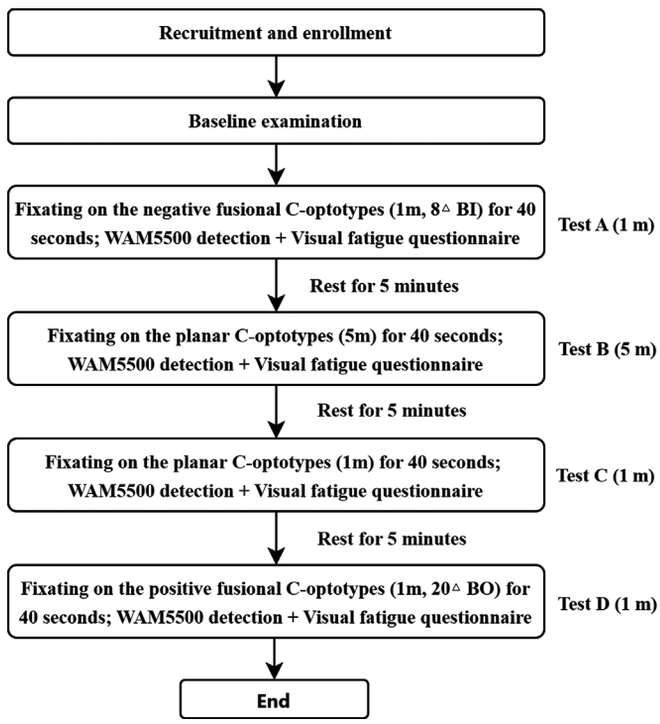

Figure 1 Flowchart of the experimental protocol BI: Base-in; BO: Base-out.

Observation Indicators

Transient accommodation TAC is defined as the real-time refractive change of the eye when focusing on targets, measured in diopters (D). A more negative value indicates a stronger accommodative response (*i.e.*, greater ciliary muscle contraction) to visual targets. The WAM-5500 open-field autorefractor was utilized to collect real-time TAC data (unit: D) from subjects across four experimental stages (Test A, Test B, Test C, Test D), with subsequent comparative analysis performed. Outliers, attributed to blinking or inattention, were identified and excluded using the boxplot[20] method [criteria: values <Q1-1.5×interquartile range (IQR) or >Q3+1.5×IQR], and only valid data were retained for further analyses.

Accommodative microfluctuations The evaluation method refers to previous research papers[21-23]. Based on the repeated measurement data of TAC, the IQR was used to quantify the fluctuation amplitude, reflecting the fluctuation range of the middle 50% of the data and measuring the absolute dispersion degree of TAC. The coefficient of variation based on the median (CV_{med}, calculated as CV_{med}=IQR/median) was used to evaluate the fluctuation stability. By standardizing the fluctuation amplitude (eliminating the influence of the median), the relative dispersion degree of TAC was measured. Both indicators indirectly reflect the short-term control ability

of the accommodation system; smaller IQR and absolute value of CV_{med} indicate stronger accommodation stability.

CA/C Calculated as the change in TAC divided by the change in convergence, with the unit of D/△.

Visual fatigue questionnaire score A visual fatigue questionnaire[24] was used to evaluate the severity of subjective visual fatigue symptoms of the subjects in each stage of Test A, B, C, and D. This questionnaire includes 10 items such as dizziness, dry eyes, and nausea, with each item scored on a scale of 0-5 (higher scores indicate more severe symptoms).

Statistical Analysis SPSS 25.0 software was used for statistical analysis. Measurement data conforming to a normal distribution were expressed as mean±standard deviation (SD) and analyzed using parametric tests; measurement data not conforming to a normal distribution were expressed as median (IQR) and analyzed using non-parametric tests. A *P*-value <0.05 was considered statistically significant.

In this study, TAC and CA/C showed a normal distribution, so they were expressed as mean±SD. Repeated-measures one-way ANOVA was used for comparison among multiple groups, and paired *t*-test was used for comparison between two groups. Accommodative microfluctuation amplitude, accommodative microfluctuation stability, visual fatigue score, and average accommodation amplitude showed a non-normal distribution, so they were expressed as median (IQR). Friedman test was used for comparison among multiple groups, and paired-sample Wilcoxon test was used for comparison between two groups.

RESULTS

Baseline Data of Subjects The baseline data of the subjects are shown in Table 1. A total of 21 subjects were included (7 males and 14 females), aged 23-41y, with normal BCVA, eye position, fusional function, accommodation function and Titmus.

In this study, the convergence requirements for the subjects in Test B and Test C stages were lower than those in Test D stage. Among them, the maximum convergence (20△ BO) set in Test D stage was within the subjects' near convergent fusion amplitude (22.38±1.24△); the maximum divergence (8△ BI) set in Test A stage was also within the near divergent fusional amplitude of the subjects (12.29±1.19△). The theoretical average accommodation amplitude of all subjects was calculated according to the formula: 18-0.3×age. No statistically significant difference was found between the measured average accommodation amplitude of the subjects 9.60 (8.85, 9.90) D and the theoretical average accommodation amplitude 9.61 (8.66, 10.13) D (F=161.500, P=0.110). In addition, the accommodation lag (0-0.50 D), Titmus (40″-60″), and heterophoria (±3△) of the subjects were all within the clinically recognized normal range. The above conditions indicate that the binocular visual function of all subjects met the implementation requirements of this study, and they had the ability to complete the study.

Table 1 Baseline data of subjects

Observation indicators (*n*=21, right eye)	Descriptive statistics
Male/female	7/14
Age (y)	28.00 (26.50, 30.50)
Spherical equivalent (D)	-3.32±1.45
BCVA, logMAR	0 (0, 0)
Distant divergent fusional amplitude (5 m, △)	7.52±1.36
Distant convergent fusional amplitude (5 m, △)	10.48±1.29
Near divergent fusional amplitude (40 cm, △)	12.29±1.19
Near convergent fusional amplitude (40 cm, △)	22.38±1.24
Average accommodation amplitude (D)	9.60 (8.85, 9.90)
Accommodation lag (D)	0-0.50 (range)
Titmus (″)	40-60 (range)
Heterophoria (△)	±3 (range)

BCVA: Best-corrected visual acuity.

Table 2 TAC across experimental groups and time segments mean±SD

Groups	Total 40s (D)	TAC		*P*
		First 20s (D)	Second 20s (D)	
Test A	-0.35±0.26	-0.31±0.26	-0.43±0.29	0.050
Test B	-0.46±0.24	-0.47±0.25	-0.50±0.29	0.450
Test C	-0.77±0.32	-0.78±0.31	-0.76±0.34	0.643
Test D	-1.38±0.31	-1.44±0.52	-1.27±0.41	0.153
P	<0.001[a]	<0.001[a]	<0.001[a]	

[a]*P*<0.001. SD: Standard deviation; TAC: Transient accommodation.

Transient Accommodation As shown in Table 2, the TAC of the subjects exhibited a gradual increasing trend from Test A to Test D, with respective values of -0.35±0.26 D (Test A), -0.46±0.24 D (Test B), -0.77±0.32 D (Test C), and -1.38±0.31 D (Test D). Among them, the TAC in Test A (fixating on the 1-meter negative fusional C-optotypes) was 0.42 D lower than that in Test C (fixating on the 1-meter planar C-optotypes), suggesting that the negative fusional C-optotypes can induce the ciliary muscle to enter a relaxed state through the mechanism of fusional accommodation. In contrast, the TAC in Test D (fixating on the 1-meter positive fusional C-optotypes) was 0.61 D higher than that in Test C, indicating that the positive fusional C-optotypes can activate the near reflex pathway, significantly enhance the contraction tension of the ciliary muscle, and provide experimental evidence for the intensive training of accommodation function.

Statistical analysis revealed a significant overall difference in TAC across the four stages (Test A-D; one-way ANOVA, F=56.136, P<0.001). Further pairwise comparisons showed no significant difference in TAC between Test A and Test B, or between Test B and Test C (all P>0.05). This suggests that the 5-meter planar C-optotypes (Test B) has a similar regulatory effect on ciliary muscle status to both the 1-meter negative fusional C-optotypes (Test A) and the 1-meter

planar C-optotypes (Test C). However, the TAC in Test A was significantly lower than that in Test C and Test D (all $P<0.05$), and the TAC in Test B and Test C was significantly lower than that in Test D (all $P<0.001$).

The above results clarified the differential effects of different target types on TAC, and the specific trend was shown in Figure 2. In addition, correlation analysis showed that there was no linear correlation between TAC and the subjects' ages in each stage (Figure 3), suggesting that in the adult population aged 23-41y included in this study, age had no significant interference with the changes in TAC induced by fusional C-optotypes.

Accommodative Microfluctuations Table 3 presented the fluctuation amplitude of TAC in the four test stages (Test A, Test B, Test C, Test D) of the subjects. The data was expressed as median and IQR, which reflects the absolute dispersion degree of TAC fluctuations. Intragroup comparison results showed that there was no statistically significant difference in the fluctuation amplitude between the first 20s and the second 20s in each stage (all $P>0.05$), indicating that within a single experimental stage, the fluctuation amplitude of the subjects' accommodation system did not change significantly with the extension of fixation time, and the temporal stability of TAC fluctuations was good. Intergroup comparison results showed that there was no statistically significant difference in the fluctuation amplitude of the total 40s, first 20s, and second 20s among the four stages (all $P>0.05$), suggesting that different target types (positive/negative fusional C-optotypes, planar C-optotypes) and target distances (1 and 5 m) had no significant impact on the fluctuation amplitude of TAC.

The absence of intergroup differences in the fluctuation amplitude of TAC in each stage of this study was presumably related to the characteristics of the subject population. The subjects included in this study were all adults with normal accommodation function; their ciliary muscle nerve regulation pathways and lens refractive accommodation systems were in a physiologically stable state, with strong self-compensation and stability maintenance capabilities. In addition, the fixation duration in each experimental stage was only 40s, and the short-term training load did not exceed the stability threshold of the normal accommodation system. Therefore, no significant difference in fluctuation amplitude was observed. If subsequent studies expand the subject population to include people with abnormal accommodation function (*e.g.*, ciliary muscle spasm, accommodation insufficiency), their accommodation systems themselves have weak stability and may be more sensitive to accommodation stimulation induced by different targets, leading to intergroup differences in fluctuation amplitude. This hypothesis needs to be further verified by subsequent studies with expanded sample sizes and heterogeneous populations.

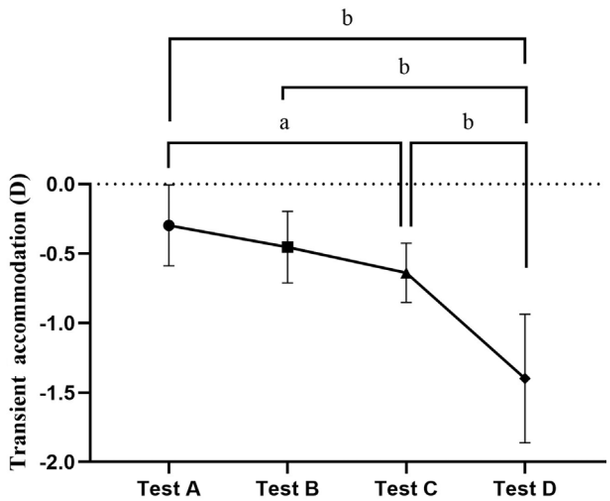

Figure 2 Comparison of transient accommodation data across experimental stages (Test A-Test D) $^{a}P<0.01$, $^{b}P<0.0001$.

Table 3 Fluctuation amplitude of TAC across experimental groups and time segments median (IQR)

Groups	Total 40s (D)	Fluctuation amplitude		*P*
		First 20s (D)	Second 20s (D)	
Test A	0.26 (0.15, 0.41)	0.21 (0.11, 0.35)	0.21 (0.09, 0.37)	0.455
Test B	0.16 (0.11, 0.35)	0.12 (0.08, 0.17)	0.14 (0.10, 0.20)	0.095
Test C	0.18 (0.11, 0.31)	0.12 (0.10, 0.25)	0.16 (0.08, 0.32)	0.889
Test D	0.21 (0.13, 0.34)	0.18 (0.09, 0.26)	0.20 (0.13, 0.37)	0.068
P	0.378	0.347	0.128	

TAC: Transient accommodation; IQR: Interquartile range.

Table 4 showed the fluctuation stability of TAC in different experimental stages (Test A, Test B, Test C, Test D). Intragroup analysis showed that there was no statistically significant difference in fluctuation stability between the first 20s and the second 20s in Test A, Test B, and Test C stages ($P>0.05$). Wilcoxon test showed that there was a statistically significant difference in fluctuation stability between the first 20s and the second 20s in Test D stage ($P=0.017$), indicating that the fluctuation stability of TAC in this stage changed dynamically with time. Intergroup analysis showed that there were statistically significant differences in fluctuation stability among groups in the total 40s ($P<0.001$) and the first 20s ($P=0.002$); there was no statistically significant difference among groups in the second 20s ($P=0.116$).

Convergence Accommodation to Convergence Table 5 showed the changes in CA/C in different experimental stages (Test A, Test D). Intragroup analysis showed no significant difference in CA/C between the first and second 20s of Test A ($P=0.070$), indicating stable accommodation-convergence linkage in this stage. In contrast, Test D showed a significantly higher CA/C in the first 20s than in the second 20s ($P=0.034$), reflecting dynamic changes in accommodation-convergence linkage during this stage. Intergroup analysis showed that the CA/C in Test D stage was significantly higher than that in Test A stage in the total 40s ($P=0.007$) and the first 20s

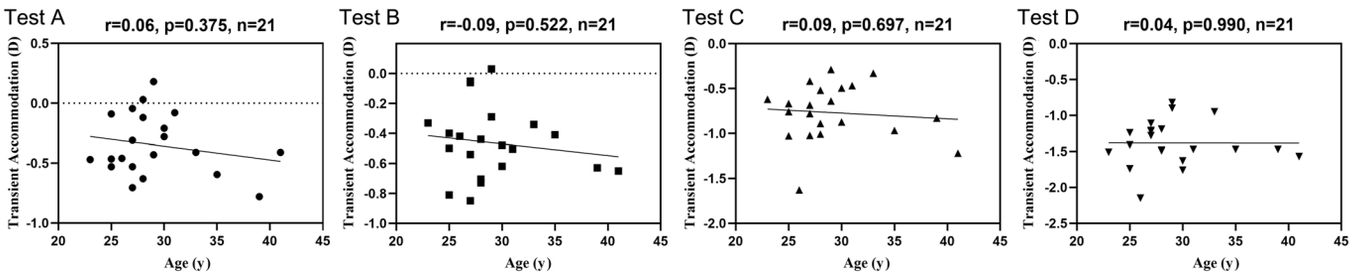

Figure 3 Correlation between age and transient accommodation across experimental stages (Test A-Test D) Pearson correlation analysis was performed; *r*: Pearson correlation coefficient.

Table 4 Fluctuation stability of TAC across experimental groups and time segments median (IQR)

Groups	Total 40s	Fluctuation stability		*P*
		First 20s	Second 20s	
Test A	-0.59 (-1.29, -0.30)	-0.51 (-1.15, -0.13)	-0.66 (-1.42, -0.20)	0.520
Test B	-0.39 (-0.92, -0.18)	-0.20 (-0.45, -0.11)	-0.30 (-0.61, -0.21)	0.073
Test C	-0.25 (-0.57, -0.13)	-0.18 (-0.38, -0.10)	-0.30 (-0.52, -0.10)	0.192
Test D	-0.17 (-0.24, -0.10)	-0.13 (-0.19, -0.08)	-0.18 (-0.27, -0.11)	0.017[a]
P	<0.001[c]	0.002[b]	0.116	

[a]*P*<0.05, [b]*P*<0.01, [c]*P*<0.001. TAC: Transient accommodation; IQR: Interquartile range.

Table 5 CA/C ratios across experimental groups and time segments

Groups	Total 40s (D/△)	First 20s (D/△)	Second 20s (D/△)	*P*
Test A	0.03±0.02	0.04±0.02	0.05±0.04	0.070
Test D	0.05±0.02	0.07±0.03	0.06±0.02	0.034[a]
P	0.007[b]	0.002[b]	0.482	

[a]*P*<0.05, [b]*P*<0.01. The CA/C data conformed to a normal distribution and were therefore expressed as mean±standard deviation. For Test A and Test D, CA/C values were calculated using Test C as the baseline, with the formula defined as follows: CA/C=ΔTAC/Δ convergence. TAC: Transient accommodation.

(*P*=0.002), indicating that the linkage between accommodation and convergence was stronger when fixating on the positive fusional C-optotypes in Test D stage. There was no significant difference between the two groups in the second 20s (*P*=0.482), which may be related to the changes in the state of the accommodation system in the later period.

Visual Fatigue Score The visual fatigue scores of the four stages (Test A, B, C, D) were 0 (0, 1), 0 (0, 0), 0 (0, 0.5), and 1 (1, 1) respectively (Figure 4). There was a statistically significant overall difference in the visual fatigue scores among the four stages (*P*<0.001). Pairwise comparison showed that the visual fatigue scores of Test B and Test C groups were significantly lower than that of Test D group, with statistically significant differences (*P*<0.05); there were no statistically significant differences in pairwise comparisons between other stages (*P*>0.05). As shown in Figure 5, the higher score in Test D was mainly driven by mild symptoms of eye strain, which may be attributed to the continuous coordinated work of the ciliary muscle and extraocular muscles during active convergence.

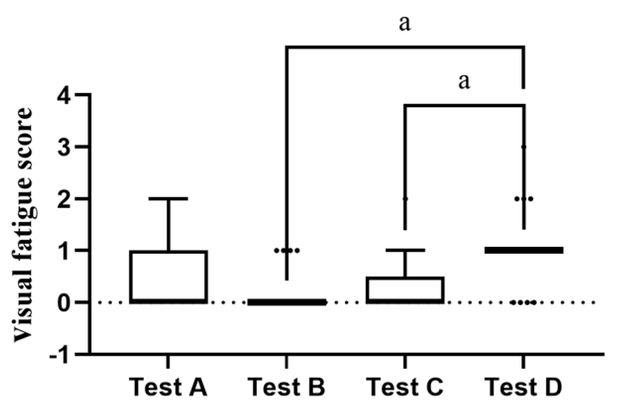

Figure 4 Comparison of visual fatigue scores across experimental stages (Test A-Test D) [a]*P*<0.05.

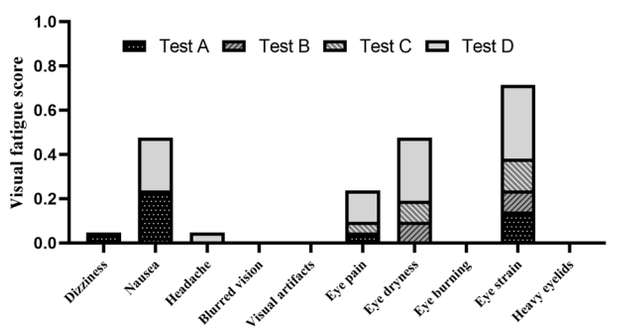

Figure 5 Subjective visual fatigue evaluation across experimental stages (Test A-Test D) by symptom scores.

DISCUSSION

This study adopted a self-controlled design (pre-post design), with 21 adults with normal accommodation function as the research subjects. The core advantage of this design is that the same subject is used as a self-control, which can fundamentally eliminate the interference of individual differences (*e.g.*, baseline levels of accommodation ability and fusional function) on the research results and significantly reduce the impact of confounding factors.

Analysis of the subjects' baseline data showed that there was no statistically significant difference between their measured average accommodation amplitude and the theoretical value (P=0.110). At the same time, the fusional function, accommodation lag (0-0.50 D), heterophoria (±3△), and Titmus (40″-60″) of all subjects were within the clinically recognized normal range, and they fully met the implementation requirements of this study. This effectively avoided data loss or bias caused by "inability to complete tasks due to abnormal baseline function".

Further analysis of the subjects' binocular visual function parameters found that their near convergence ability (22.38±1.24△) could fully cover the maximum convergence (20△ BO) set in Test D stage, and their near divergence ability (12.29±1.19△) could also cover the maximum divergence (8△ BI) set in Test A stage. Combined with the result that there was no difference between the measured values and theoretical values of accommodation amplitude, it was fully ensured that all subjects could stably tolerate and complete the experiments in each stage, providing key guarantee for the validity and reliability of the research results at the baseline level.

Analysis of Main Research Results The TAC showed a gradual increase trend from Test A (-0.35±0.26 D) to Test D (-1.38±0.31 D). This result was not simply driven by the change in target distance but originated from the differential activation of the "ciliary muscle-nerve regulation pathway" by targets with different characteristics in each experimental stage.

In Test A (fixating on the 1-meter 8△ BI negative fusional C-optotypes), the negative fusional C-optotypes enable the two eyes to receive targets with uncrossed parallax *via* red-blue dichoptic viewing. After brain fusion, the target's perceived distance is farther than its physical 1-meter distance. This visual illusion (perceived distance >actual distance) reversely regulates the ciliary muscle *via* fusional accommodation: when the brain perceives the target as distant, it inhibits cholinergic neurotransmitter release from the midbrain Edinger-Westphal (E-W) nucleus. This inhibition reduces ciliary muscle contraction tension, decreases lens refractive power, and ultimately achieves accommodation relaxation. This aligns with Huang *et al*[25], who reported that autostereoscopic 3D viewing reduced lens thickness in myopes; our study extended this finding by demonstrating that negative fusional C-optotypes further induced ciliary muscle relaxation—evidenced by a 0.42 D lower TAC compared to planar targets (Test C, P<0.05)—providing a targeted relaxation mechanism for myopia control. The divergence set in the experiment was within the subjects' near divergence ability, which not only avoided visual fatigue caused by excessive divergence but also stably activated the "divergence-accommodation relaxation" synergistic effect, ensuring controllable relaxation effect.

From the perspective of objective indicators, the TAC in Test A was -0.35±0.26 D, which was significantly lower than that in Test C (fixating on the 1-meter planar C-optotypes, -0.77±0.32 D, P<0.05) and Test D (fixating on the 1-meter positive fusional C-optotypes, -1.38±0.31 D, P<0.001). The fluctuation amplitude in Test A was 0.26 (0.15, 0.41) D, and the fluctuation stability was -0.59 (-1.29, -0.30). There were no significant differences in fluctuation amplitude (P=0.455) and fluctuation stability (P=0.520) between the first 20s and the second 20s, indicating that the accommodation system maintained a stable relaxed state.

There was no statistically significant difference in TAC between Test A and Test B, or between Test B and Test C (all P>0.05), but the TAC in Test A was significantly lower than that in Test C (P<0.05), suggesting that the TAC in the three stages (Test A, Test B, Test C) showed a stepwise increase trend, and a statistically significant difference was observed only when the accommodation load accumulated to Test C stage. This pattern clearly demonstrates the differential effects of different target types on the ciliary muscle state. The 1-meter negative fusional target in Test A was perceived as a farther virtual image, and its relaxation effect on the ciliary muscle was the strongest—at this time, the near accommodation demand signal received by the brain was the weakest, and the ciliary muscle was in a low-tension relaxed state, with TAC maintained at the lowest level. Although the 5-meter planar target in Test B was presented at a long distance (theoretical accommodation demand was close to -0.2 D), compared with the "active relaxation" effect of Test A, the static long-distance target still required the ciliary muscle to maintain basic refractive stability, so the TAC was slightly higher than that in Test A. The 1-meter planar target in Test C had a significantly increased near accommodation demand due to the shortened actual distance, and the ciliary muscle needed to increase the contraction tension to meet the focusing demand, so the TAC further increased, eventually forming a statistically significant difference with Test A. It can be seen that the negative fusional C-optotypes in Test A exhibited the optimal effect in inducing ciliary muscle relaxation. In contrast, planar C-optotypes (both at 5 and 1 m) consistently imposed an accommodative demand, primarily due to the absence of an "active relaxation drive". Furthermore, as the target distance shortened, both the accommodative demand and the intensity of ciliary muscle contraction showed a gradual increasing trend.

The TAC in Test D stage (1-meter 20△ BO positive fusional C-optotypes) was -1.38±0.31 D, which was significantly higher than that in the other three stages (P<0.001). This was due to the crossed parallax design of the positive fusional target: after the two eyes received the crossed parallax signals, the brain perceived the target distance as closer than the physical

distance of 1 m, thereby activating the near reflex pathway and promoting the active contraction of the ciliary muscle[26-28] and the medial rectus muscle, realizing the synchronous activation of accommodation and convergence. The convergence set in the experiment was within the subjects' near convergence ability, ensuring that accommodation activation was within the physiological load and avoiding ciliary muscle spasm caused by excessive contraction.

The CA/C ratio in Test D was significantly higher than that in Test A (total 40s: 0.05±0.02 *vs* 0.03±0.02 D/△; first 20s: 0.07±0.03 *vs* 0.04±0.02 D/△; all $P<0.01$). Additionally, Test D showed a significantly higher CA/C in the first 20s than in the second 20s ($P=0.034$). The CA/C ratio represents the linkage efficiency between TAC and convergence; its increase confirms that positive fusional fixation enhances the neural coordinated control between the ciliary muscle and the medial rectus muscle—the accommodation-convergence linkage response was faster in the first 20s, and slightly decreased in the second 20s due to the adaptive adjustment of the accommodation system, but the overall coordination was still better than that in Test A. Test D was the only stage where there was a significant difference in fluctuation stability between the first 20s and the second 20s ($P=0.017$); the fluctuation stability in the first 20s was -0.13 (IQR: -0.19, -0.08), which was better than that in the second 20s (-0.18; IQR: -0.27, -0.11). This difference may be attributed to slight ciliary muscle fatigue in the later period, which led to reduced stability.

Based on the accommodation activation effects of Test A and Test D, a "relaxation-activation" dual-directional accommodation training program can be constructed to address different types of accommodation dysfunction. For people with ciliary muscle spasm caused by prolonged near-work, a combined training of "Test A (fixating on the 1-meter negative fusional C-optotypes)+Test B (fixating on the 5-meter planar C-optotypes)" is adopted, with 10-15min per session (including 5 cycles of 40s Test A) and once a day. The relaxation effect of the negative fusional target is used to relieve spasm. For people with accommodation insufficiency and decreased CA/C ratio, a combined training of "Test D (fixating on the 1-meter positive fusional C-optotypes)+Test C (fixating on the 1-meter planar C-optotypes)" is adopted, with 10min per session (including 4 cycles of 40s Test D) and once a day. The positive fusional target is used to enhance the coordination of accommodation and convergence.

In addition, there was no linear correlation between TAC and age in each stage. This finding appeared inconsistent with the classic observation[29] that "accommodation declines with age after 30y"; however, this discrepancy likely arose from the narrow age range (23-41y) and normal accommodative function of all subjects, which minimized age-related variations in TAC.

In this study, there was a statistically significant overall difference in visual fatigue scores among the four stages (Test A, B, C, D; $P<0.05$), but the scores in each stage were at a low level (median: 0-1 point). Only the scores of Test B and Test C (median: 0 point) were significantly lower than that of Test D (median: 1 point; $P<0.05$), and there were no statistically significant differences between other stages ($P>0.05$). This result highlights the safety of this method. The lowest score observed in the Test B stage (5-meter planar target) can be attributed to the fact that the "5-meter planar target" aligns with the ocular physiological hygiene principle of "viewing distant objects to achieve ocular relaxation", and both the ciliary muscle and extraocular muscles were in a low-load state. The slightly higher score in Test D stage (1-meter positive fusional target) was related to the continuous coordinated work of the ciliary muscle and extraocular muscles during "active convergence". This conclusion is consistent with the results of previous studies[30], and the median score of 1 point belongs to the category of no obvious visual fatigue, indicating that even in the convergence fixation stage with the highest intensity, no obvious discomfort was caused to the subjects within a short period of time.

Comparison with Existing Myopia Prevention and Control Methods Among the current myopia prevention and control methods, the use of atropine requires strict dose control and there is insufficient long-term safety data. Orthokeratology lenses are greatly affected by individual corneal morphology and have high compliance requirements (*e.g.*, night wear, regular reexamination).

This study focuses on the "ciliary muscle function", a key link in the occurrence and development of myopia. The study found that fixating on positive fusional C-optotypes can significantly increase TAC, while fixating on negative fusional C-optotypes can significantly decrease TAC. This suggests that positive/negative fusional C-optotypes can improve the transient contraction and relaxation functions of the ciliary muscle through differential training, thereby providing a new "function-improving" idea for myopia prevention and control.

At the same time, the non-invasive software training mode adopted in this study did not require contact with the ocular surface throughout the process, fundamentally avoiding the side effects of orthokeratology lenses and atropine. Moreover, in each experimental stage, the subjects' visual fatigue scores were low (median≤1 point), which fully reflected the good comfort and tolerance of this training method.

In summary, by exploring the association between ciliary muscle function improvement and myopia prevention and control, this study not only provides a new safe and comfortable intervention program but also provides experimental evidence for the development of myopia

prevention and control from "passive control" to "active function optimization".

Study Limitations This study had several limitations. First, the sample size was relatively small, and the subjects were limited to adults with normal accommodative function, which restricted the direct generalization of the conclusions to myopic adolescents (a high-risk population for myopia) or individuals with abnormal accommodative function. Second, only a single intervention mode was used, which precluded the evaluation of the long-term sustainability of the accommodative improvement effect. Third, the study only monitored TAC and visual fatigue scores during the experiment, and did not detect neuroelectrophysiological changes in the visual cortex. This limited the ability to fully elucidate the mechanism by which positive/negative fusional C-optotypes contributed to myopia prevention and control.

To address these limitations, future studies will adopt the following strategies: First, the sample size will be expanded, and participants will be extended to include myopic adolescents (the high-risk population for myopia progression) and individuals with abnormal accommodative function (*e.g.*, ciliary muscle spasm, accommodative insufficiency). This will verify the generalizability of the current findings across diverse populations. Second, a 6-month to 1-year longitudinal follow-up protocol will be designed to monitor the long-term stability of accommodative function post-training and its potential impact on myopia progression, which will fill the gap in evaluating the sustainability of the intervention effect. Third, event-related potential (ERP) recordings of the visual cortex will be integrated to explore the neurophysiological mechanisms underlying the effects of positive/negative fusional C-optotypes on accommodative function. This addition will further strengthen the evidence base and deepen the understanding of the causal links between fusional training and myopia control.

In conclusion, the fusional training software based on red-blue 3D technology can induce near accommodation relaxation through Test A (fixating on negative fusional C-optotypes) and optimize the coordination and dynamic stability of accommodation-convergence through Test D (fixating on positive fusional C-optotypes), with good safety. Although there are limitations such as small sample size and lack of long-term follow-up, this study still opens up a new path for myopia prevention and control. Subsequent studies need to promote its clinical transformation through higher-quality research to help solve the global problem of myopia prevention and control.

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REFERENCES

1 Shah R, Vlasak N, Evans BJW. High myopia: reviews of myopia control strategies and myopia complications. *Ophthalmic Physiol Opt* 2024;44(6):1248-1260.

2 Ha A, Kim CY, Shim SR, *et al*. Degree of myopia and glaucoma risk: a dose-response meta-analysis. *Am J Ophthalmol* 2022;236:107-119.

3 Zhang XL, Jiang JW, Kong KJ, *et al*. Optic neuropathy in high myopia: Glaucoma or high myopia or both *Prog Retin Eye Res* 2024;99:101246.

4 Liang JH, Pu YQ, Chen JQ, *et al*. Global prevalence, trend and projection of myopia in children and adolescents from 1990 to 2050: a comprehensive systematic review and meta-analysis. *Br J Ophthalmol* 2025;109(3):362-371.

5 Pan W, Saw SM, Wong TY, *et al*. Prevalence and temporal trends in myopia and high myopia children in China: a systematic review and meta-analysis with projections from 2020 to 2050. *Lancet Reg Health West Pac* 2025;55:101484.

6 Meng ZY, Yang L, Zhou P. Ciliary muscles contraction leads to axial length extension—the possible initiating factor for myopia. *PLoS One* 2024;19(4):e0301844.

7 Prousali E, Haidich AB, Tzamalis A, *et al*. The role of accommodative function in myopic development: a review. *Semin Ophthalmol* 2022;37(4):455-461.

8 Landreneau JR, Hesemann NP, Cardonell MA. Review on the myopia pandemic: epidemiology, risk factors, and prevention. *Mo Med* 2021;118(2):156-163.

9 Logan NS, Radhakrishnan H, Cruickshank FE, *et al*. IMI accommodation and binocular vision in myopia development and progression. *Invest Ophthalmol Vis Sci* 2021;62(5):4.

10 Sartor L, Hunter DS, Vo ML, *et al*. Benefits and risks of orthokeratology treatment: a systematic review and meta-analysis. *Int Ophthalmol* 2024;44(1):239.

11 Zhang GH, Jiang J, Qu C. Myopia prevention and control in children: a systematic review and network meta-analysis. *Eye (Lond)* 2023;37(16): 3461-3469.

12 Sun H, Bu FJ, Xin X, *et al*. Incidence of adverse events induced by atropine in myopic children: a meta-analysis. *J Clin Pharmacol* 2023;63(12):1377-1386.

13 Li H, Xu Y, Li L. Efficacy and safety of orthokeratology lenses for the management of adolescent myopia: a Meta-analysis. *Altern Ther Health Med* 2023;29(7):172-177.

14 Simmons JM, Firth AY. Convergence accommodation to convergence CA/C ratio: convergence versus divergence. *Strabismus* 2014;22(3):120-124.

15 Nonaka F, Hasebe S, Ohtsuki H. Convergence accommodation to convergence (CA/C) ratio in patients with intermittent exotropia and decompensated exophoria. *Jpn J Ophthalmol* 2004;48(3):300-305.

16 Molina R, Redondo B, Molina-Carballo A, *et al*. Capturing attention improves accommodation: an experimental study in children with ADHD using multiple object tracking. *Vis Res* 2021;186:52-58.

17 Vera J, Redondo B, Galan T, *et al*. Dynamics of the accommodative response and facility with dual-focus soft contact lenses for myopia control. *Contact Lens Anterior Eye* 2023;46(1):101526.

18 Du QX, Zhang Y, Huang YS. Peripheral refraction and axial growth rate after multifocal or monofocal intraocular lens implantation in Chinese pediatric cataract patients. *Invest Ophthalmol Vis Sci* 2025;66(2):33.

19 Redondo B, Serramito M, Vera J, *et al*. Diurnal variation in accommodation, binocular vergence, and pupil size. *Optom Vis Sci* 2023;100(12):847-854.

20 Garlits J, McAfee S, Taylor JA, *et al*. Statistical approaches for establishing appropriate immunogenicity assay cut points: impact of sample distribution, sample size, and outlier removal. *AAPS J* 2023;25(3):37.

21 Kaida T, Ono T, Tokunaga T, *et al*. Prevalence of accommodative microfluctuations in eyes after cataract surgery. *J Clin Med* 2023;12(15):5135.

22 Lin HL, Drobe B, Jin WQ, *et al*. Effects of near addition lenses and prisms on accommodative microfluctuations in Chinese children. *Optom Vis Sci* 2016;93(5):488-496.

23 Charman WN, Heron G. Fluctuations in accommodation: a review. *Ophthalmic Physiol Opt* 1988;8(2):153-164.

24 Huang YY, Li MY, Shen Y, *et al*. Study of the immediate effects of autostereoscopic 3D visual training on the accommodative functions of myopes. *Invest Ophthalmol Vis Sci* 2022;63(2):9.

25 Huang YY, Ten W, Zhan BY, *et al*. Autostereoscopic3Dviewing can change the dimensions of the crystalline lens in myopes. *Ophthalmic Physiologic Optic* 2024;44(6):1309-1318.

26 Fogt N, Toole AJ, Rogers DL. A review of proximal inputs to the near response. *Clin Exp Optom* 2016;99(1):30-38.

27 Rosenfield M, Ciuffreda KJ. Proximal and cognitively-induced accommodation. *Ophthalmic Physiologic Optic* 1990;10(3):252-256.

28 Hung GK, Ciuffreda KJ, Rosenfield M. Proximal contribution to a linear static model of accommodation and vergence. *Ophthalmic Physiologic Optic* 1996;16(1):31-41.

29 Sun FC, Stark L, Nguye AN, *et al*. Changes in accommodation with age: static and dynamic. *Optom Vis Sci* 1988;65(6):492-498.

30 Huang YY, Menozzi M, Lee CY. Vergence-accommodation conflict: increased presbyopia in virtual reality. *Klin Monbl Augenheilkd* 2024;241(4):540-544.