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Relumino mode may provide video terminal assistance for the amblyopic patients

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This study aimed to assess whether Relumino mode TV could assist amblyopic patients using video terminals. This mode utilizes real-time image processing techniques to enhance visual effects. We recruited 38 participants with anisometropic amblyopia, all literate and cognitively capable. The Modulation Transfer Function (MTF) of the normal and Relumino modes was measured to evaluate the relationship between spatial frequency variations and visual effects. All participants underwent tests for visual acuity, reading performance (reading speed and accuracy), and viewing three 5-min videos in both modes. Afterward, they completed a Visual Function Evaluation Questionnaire. A total of 38 volunteers (mean age, 17.0 ± 13.3 years) completed this study. The results indicated that in Relumino mode, the visual scores for static images and videos with lower MTF were 5.58 ± 1.66 ($p = 0.038$) and 5.33 ± 1.42 ($p = 0.167$), respectively, suggesting better visual function with Relumino mode, compared to the normal mode. However, no significant changes were found in the LogMAR mean values for amblyopic eyes (from 0.47 ± 0.26 to 0.49 ± 0.26, $p = 0.237$), reading speed (from 68.62 ± 59.13 to 74.39 ± 59.78, $p = 0.209$) or reading accuracy (from 0.96 ± 0.12 to 0.92 ± 0.17, $p = 0.019$) before and after using Relumino mode. There was no significant improvement in visual functions related to text on the screen. This study suggests that the Relumino mode enhances the visual experience for amblyopic patients when watching videos or images on the TV, especially compared to the normal mode.

Keywords Amblyopia, Binocular vision, Visual deficits, Spatial frequency, Amblyopia care device

Amblyopia is defined as reduced best-corrected visual acuity resulting from abnormal visual development during the critical period of visual cortex neurodevelopment[1]. Patients with amblyopia typically experience imbalanced neural processing and permanent visual deficits due to unequal visual input from both eyes[2]. This often leads to poor binocular visual function, affecting perceptual, oculomotor, and neural functions[3–5]. The condition is most commonly caused by anisometropia (50%), followed by strabismus (19%), a combination of both (27%), and/or form-deprivation amblyopia (4%)[6–9]. In this study, we focus on the most common one, anisometropia.

Amblyopic patients often experience various unexplained visual complaints that are challenging for clinicians to quantify and define objectively. Apart from providing appropriate treatments for patients, these uncomfortable visual sensations often trouble patients. Amblyopia affects visual acuity, contrast sensitivity, and fixation stability in the affected eye. It also leads to decreased stereoacuity and increased susceptibility to 'crowding,' making it difficult to identify shapes amid visual clutter[2,10,11]. In contrast, patients with significant inter-ocular visual acuity often see monocularly better than binocularly, termed binocular inhibition[12–14]. This means the better-seeing eye exerts an inhibitory influence over the amblyopic eye during binocular viewing[2]. Moreover, even treated amblyopes often do not regain normal binocular vision and continue to experience binocular dysfunction in daily life[3,14–17], which can decrease their quality of life due to these functional deficits[18].

Emerging evidence suggests that various visual deficiencies manifest as reduced contrast sensitivity, particularly at higher spatial frequencies[16]. They found that amblyopic patients have significant disruption in binocular imbalance across all spatial frequencies. However, the higher the spatial frequency is, the greater the binocular imbalance observed in amblyopic patients[19,20]. Spatial frequency is the number of wave cycles per unit distance, typically measured to assess a display's resolution. In optics and image processing, the Modulation

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Transfer Function (MTF) is often used to evaluate an imaging system's resolution. Therefore, MTF can be used to represent the spatial frequency of a display.

We take television as an example, as it is one of the most used entertainment devices for children and adults. Research has shown that amblyopic patients experience more abnormal binocular vision and systemic discomfort than people without amblyopia while watching TV. They are more prone to eye fatigue and headaches because they must exert additional efforts, such as fusional vergence and accommodation, to maintain fusion because of visual deficits[21,22]. Additionally, some amblyopic individuals experience blurred vision, difficulty focusing, transient visual dimness after watching TV, and trouble tracking motion on the screen.

A specialized amblyopia care mode called Relumino Mode was designed to alleviate these abnormal symptoms while using television. This mode improves abnormal binocular vision through several methods: (1) Adjusting contrast and brightness to enhance image quality. (2) Applying a color filter to reduce light glare. (3) Changing background and font colors to facilitate reading. (4) Outlining obscured images to help recognize objects or people. (5) Fitting the entire image within the visual field for users with tunnel vision.

This study aimed to investigate whether Relumino Mode can improve binocular dysfunction in amblyopic patients and whether this improvement is related to changes in spatial frequency.

Results

Demographic characteristics

A total of 38 amblyopic patients participated in this study. On average, the participants were 17.0 ± 13.3 years of age, including children (50%) and adults (45%). The mean spherical equivalent of cycloplegic refraction of the amblyopic eye was + 1.99 ± 3.07 D. The majority of the participants have moderate amblyopia (LogMAR 0.3–0.7, 58%), and 17 of them don't have stereoacuity (Table 1).

MTF of Relumino mode is lower than the normal mode

We obtained the luminance of the white grill (Lw) and the black grill (Lb) of the vertical-horizontal grating through 10 random tests on the screen in two modes. The measurement results are in Table 2. The mean value of MTF is also presented in Fig. 1. Quantitative analysis revealed distinct MTF profiles (Table 2): under 4 pairs of black and white grills, the Normal mode exhibited significantly higher horizontal MTF is 0.4594 and vertical MTF is 0.8936, whereas Relumino mode showed reduced and balanced MTF values for both orientations (H-MTF = 0.3411, V-MTF = 0.3428). It is evident that the MTF of the Relumino mode is lower than the Normal mode.

Characteristic	N (%) (n = 38)
Female	18 (47)
Male	20 (53)
Age at randomization	
Range	5–62
Mean (*SD*)	17 (13.3)
Age groups	
Child, 5–12	19 (50)
Teenager, 13–17	2 (5)
Adult, ≥ 18	17 (45)
Spherical equivalent of cycloplegic refraction, mean (*SD*)	
Amblyopic eye, diopters	+ 1.99 (3.07)
Fellow eye, diopters	− 0.55 (2.46)
Astigmatism, mean (*SD*)	
Amblyopic eye, diopters	− 1.04(0.99)
Fellow eye, diopters	− 0.77(0.85)
Distance VA, mean (*SD*), LogMAR	
Amblyopic eye VA	0.39 (0.20)
Range	0.2 ~ 1.0
Fellow eye VA	0.03 (0.10)
Range	− 0.1 ~ 0.3
Stereoacuity (Randot Stereotest)	
Nil stereoacuity	17 (45)
Degree of amblyopia	
Mild (LogMAR 0.1–0.2)	13 (34)
Moderate (LogMAR 0.3–0.7)	22 (58)
Severe (LogMAR > 0.7)	3 (8)

Table 1. Baseline characteristics of participants at randomization. SD standard deviation; VA visual acuity.

	Grill	H-MTF	V-MTF	HLw	HLb	VLw	VLb
Normal mode MTF	1 × 1	0.7339	0.8944	229.41	36.10	204.24	11.44
	2 × 2	0.3295	0.8929	67.05	35.38	207.89	11.88
	3 × 3	0.0922	0.8883	69.66	57.94	210.03	12.43
	4 × 4	0.4594	0.8936	71.60	26.52	210.13	11.80
Relumino mode MTF	1 × 1	0.1090	0.1345	235.28	189.82	238.50	183.91
	2 × 2	0.0322	0.026	238.13	224.16	238.12	226.58
	3 × 3	0.3373	0.2262	213.51	144.88	224.50	164.98
	4 × 4	0.3411	0.3428	205.74	121.18	220.80	133.90

Table 2. The measurement results of normal mode MTF and Relumino mode MTF. MTF Modulation Transfer Function; H-horizontal; V- vertical; Lw luminance of the white grill; Lb luminance of the black grill.

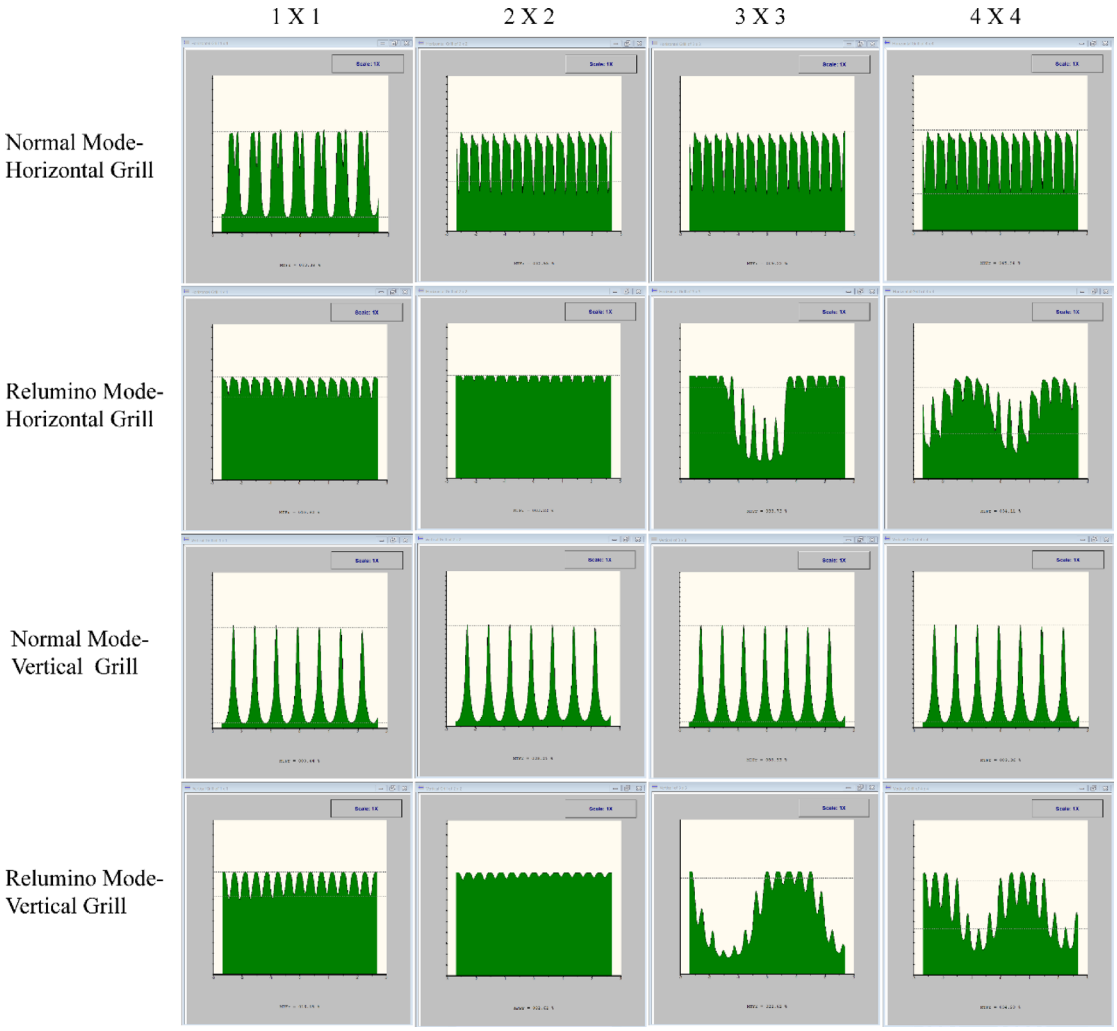

Fig. 1. The MTF of 1–4 pairs of black and white vertical-horizontal grill in normal and Relumino mode.

No significant improvement in reading performance with Relumino mode

Two objective assessments in our study including distance visual acuity (VA) and reading speed/accuracy. The results of the LogMAR mean values for amblyopic eyes changed from 0.47 ± 0.26 to 0.49 ± 0.26 ($p = 0.237$), the mean speed of text reading changed from 68.62 ± 59.13 to 74.39 ± 59.78 ($p = 0.209$) and the mean accuracy of text reading changed from 0.96 ± 0.12 to 0.92 ± 0.17 ($p = 0.019$) before and after using Relumino mode (Table 3).

Enhanced visual experience of viewing images or videos with Relumino mode

Our study conducted a subjective evaluation in Visual Function Evaluation Questionnaire (VFEQ)[23] (Supplementary Table S1, n = 38), and the analysis of the questionnaire was as follows:

Parameter	Before (normal mode)	After (Relumino mode)	*P* value
Distance VA on screen, mean (*SD*), LogMAR			
Amblyopic eye VA	0.47 (0.26)	0.49 (0.26)	0.237
Fellow eye VA	0.17 (0.23)	0.22 (0.23)	0.071
Reading 75 words			
Reading duration (seconds), mean (*SD*)	68.62 (59.13)	74.39 (59.78)	0.209
Reading accuracy, % mean (*SD*)	0.96 (0.12)	0.92 (0.17)	0.019*

Table 3. Changes in main outcome measures between normal mode and Relumino mode in participants (n = 38). *:$p < 0.05$.

Parameter	Score(N = 38) Min(1)—Max(10)	Mean (*SD*)	T	*p* value
1. Static images	2.33–9.33	5.58 (1.66)	2.153	0.038*
2. Videos	2.00–9.00	5.33 (1.44)	1.409	0.167
3. Text	1.67–8.33	3.95 (1.64)	− 3.958	0.000***
4. Subtitles	1.00–7.00	2.61 (1.26)	− 11.628	0.000***
5. Overall evaluation	1.00–9.50	3.96 (2.23)	− 2.880	0.007**

Table 4. The score of different dimensions of visual function evaluation questionnaire (VFEQ). Evaluation standard (One-sample t-test). Part 1–4: < 5—Relumino mode is worse than normal mode; 5—No difference; > 5—Relumino mode is better than normal mode. Part 5: 1–10 (1 no improvement, 10 means great improvement). *:$p < 0.05$, **:$p < 0.01$, ***:$p < 0.001$.

Parameter	Age 6–12	Age 13–18	Age > 18	*F*	*p* value
Static images	5.30 (1.63)	6.17 (4.48)	5.82 (1.38)	0.569	0.571
Videos	5.32 (1.44)	6.00 (0.71)	5.26 (1.54)	0.225	0.799
Text	3.79 (1.59)	3.50 (0.71)	4.18 (1.80)	0.997	0.731
Subtitles	2.87 (1.59)	3.25 (1.06)	2.24 (0.71)	1.434	0.252
Overall evaluation	3.95 (2.06)	6.25 (4.60)	3.71 (2.15)	1.182	0.319

Table 5. 3 Age groups—Children, Teenagers, Adults. Evaluation standard (One-Way ANOVA).

Parameter	Mild	Moderate	Severe	*F*	*p* value
Static images	5.33 (1.62)	5.71 (1.80)	5.58 (1.13)	0.194	0.825
Videos	4.92 (2.03)	5.48 (1.12)	5.75 (0.87)	0.771	0.470
Text	4.08 (1.89)	3.70 (1.50)	4.92 (1.55)	0.997	0.379
Subtitles	2.21 (1.64)	2.89 (1.03)	2.25 (0.96)	1.317	0.281
Overall evaluation	3.83 (2.61)	4.05 (2.05)	3.88 (2.56)	0.037	0.964

Table 6. Degree of amblyopia. Evaluation standard (One-Way ANOVA).

1. Situation Analysis: The mean scores of static images and videos in this questionnaire were 5.58 ± 1.66 ($p = 0.038$) and 5.33 ± 1.42 ($p = 0.167$), which means that the visual function of Relumino mode on screen is better than normal mode, particular in static image rendering. The mean scores of text reading, subtitles viewing in this questionnaire were 3.95 ± 1.64 ($p = 0.000$) and 2.61 ± 1.26 ($p = 0.000$), which means that the visual function of static text and dynamic subtitles on screens with Relumino mode is worse than that on normal screens. The overall evaluation of Relumino mode yielded a mean score of 3.96 ± 2.23 ($p = 0.007$). (Table 4)
2. Demographic Differences Comparison: We want to find the correlation between diverse demographic characteristics and various score evaluations. Through comparisons among diverse subject groups, it was observed that visual function improvement and satisfaction with the Relumino mode showed no significant differences across age groups (Table 5), amblyopia severity (Table 6), or stereopsis status (Table 7). However, stratification by astigmatism severity (low: ≤ 1.00 D; moderate: 1.00–2.00 D; high: > 2.00 D) revealed significant associations with specific outcomes (Table 8). The results demonstrated statistically significant differences in the evaluations of Static Images ($p = 0.019$) and Overall Evaluation ($p = 0.014$) among participants stratified by astigmatism severity. Notably, participants with high astigmatism demonstrated significantly

Parameter	Stereoacuity	Nil stereoacuity	T	*p* value
Static images	5.33 (1.73)	5.95 (1.57)	− 1.135	0.264
Videos	5.07 (1.65)	5.73 (0.94)	− 1.418	0.165
Text	4.09 (1.66)	3.73 (1.63)	0.645	0.523
Subtitles	2.30 (1.29)	3.07 (1.10)	− 1.879	0.068
Overall evaluation	3.67 (2.47)	4.40 (1.77)	− 0.983	0.332

Table 7. Stereoacuity. Evaluation standard (Independent Samples T-test).

Parameter	Low	Moderate	High	*F*	*p* value
Static images	5.24 (1.54)	5.33 (1.48)	7.28 (1.47)	4.445	0.019*
Videos	5.02 (1.51)	5.83 (0.98)	6.17 (1.13)	2.106	0.137
Text	3.65 (1.52)	4.72 (1.85)	4.44 (1.86)	1.391	0.262
Subtitles	2.34 (1.10)	3.42 (2.01)	2.92 (0.66)	2.081	0.140
Overall evaluation	3.33 (1.89)	4.58 (2.48)	6.08 (2.18)	4.858	0.014*

Table 8. Degree of astigmatism. Evaluation standard (One-Way ANOVA), *:$p < 0.05$.

higher mean scores in Relumino mode for Static Images (7.28 ± 1.47), Videos (6.17 ± 1.13, $p = 0.015$), and Overall Evaluation (6.08 ± 2.18, $p = 0.013$) compared to those with low astigmatism.

Discussion

Our results suggest that Relumino mode may assist amblyopic patients by enhancing visual functions for images and videos on television screens. This indicates that this new mode has significant potential in alleviating symptoms of binocular dysfunction caused by amblyopia when using television screens.

Our study, investigated whether Relumino mode can improve visual function in patients with anisometropic amblyopia. They usually suffer a lot from large inter-ocular visual acuity, which leads to binocular imbalance[19]. As a result, they often experience greater binocular deficits such as blurred vision, difficulty focusing, and trouble tracking motion after prolonged screen time compared to the average person. There are three potential mechanisms for these deficits: reduced input in the amblyopic eye[24]; imbalanced interocular contrast sensitivity, or inhibitory interactions between the amblyopic and fellow eyes[14,25]. Mao et al.[19] found that binocular balance is more disrupted at higher spatial frequencies in amblyopia. Hence, we first measured whether spatial frequencies changed under the two modes[19,20]. Our test results (Fig. 1) revealed that the spatial frequency under the Relumino mode was much lower than that under the normal mode, supporting our hypothesis that the Relumino mode may benefit binocular function.

In addition, we evaluated changes in binocular visual function after using the two modes through objective examinations and subjective questionnaires. Firstly, there were no significant changes in visual acuity between the two modes. Some research has proven that differences in reading speed can assess binocular status[26]. Based on this evidence, we included a paragraph in our study to test reading speed and efficiency. However, we observed that the reading speed and accuracy in Relumino mode (reading speed 74.39 ± 59.78; accuracy 0.96 ± 0.12) were worse than in normal mode (reading speed 68.62 ± 59.13; accuracy 0.92 ± 0.17). Clinically, these differences are almost negligible. Some patients found that the larger font sizes made the letter outlines more prominent, while smaller or more compact text became harder to discern in Relumino mode. This feature aligns with the design concept of emphasizing contrast in Relumino mode to help patients improve the subjective comfort of reading. However, it cannot provide practical visual assistance for reading text.

Due to the difficulty in quantifying visual functions and the importance of subjective perception for amblyopic patients using the Relumino mode, we designed a questionnaire. The results confirmed its reliability. Based on statistical analysis results of the questionnaire, we found that the Relumino mode provides a better visual experience for amblyopic patients compared to the normal mode when watching videos (Score 5.33 ± 1.44) or viewing images (Score 5.58 ± 1.66) on TV, making the pictures appear brighter and more vivid. However, reading static (Score 3.95 ± 1.64) or dynamic text (Score 2.61 ± 1.62), tends to cause more discomfort. This suggests that while Relumino mode is helpful for audio-visual entertainment on TV, it is less effective for character display.

The results also indicate that factors such as age, amblyopia severity, and stereopsis presence do not significantly influence visual function in Relumino mode. However, evidence suggests that visual discomfort is associated with the severity of amblyopia and stereopsis[26]. Specifically, recent studies demonstrate that amblyopic patients retaining normal stereopsis are more susceptible to vergence-accommodation conflicts, which exacerbate ocular fatigue and headaches[27]. Additionally, incomplete interocular suppression in amblyopia may induce binocular image disparity; clinical data show that image size differences exceeding 1%-3% can trigger asthenopia, vertical diplopia, and cephalalgia[28]. Emerging interventions targeting interocular suppression modulation have shown promise in alleviating these symptoms[29].

Notably, our stratification by astigmatism severity revealed distinct outcomes. Patients with high astigmatism (> 2.00 D) reported significantly better visual performance for Static Images ($p = 0.015$) and higher Overall Evaluation scores ($p = 0.013$) compared to low astigmatism groups (Table 8). This discrepancy may stem

from meridional anisotropy in neural processing caused by long-term uncorrected astigmatism. Prior studies demonstrate that high astigmatism induces orientation-specific visual deficits, increasing amblyopia risk, and weakens neural responses to visual stimuli due to cortical maladaptation[30,31].

The observed improvement with Relumino mode likely arises from its contrast-enhancement algorithms, which selectively amplify edge details and optimize spatial frequency distribution. These adjustments appear to counteract neural meridional anisotropy, a phenomenon further supported by our MTF results (Table 2). Vertical MTF significantly exceeded horizontal MTF in normal mode, whereas Relumino mode minimized this disparity. This trend aligns with Leung et al.'s proposed adaptive bidirectional recalibration in astigmatic vision: the brain enhances contrast sensitivity along chronically blurred meridians (e.g., horizontal) while suppressing sensitivity along clearer axes (e.g., vertical)[32].

For patients with severe astigmatism, whose pronounced horizontal-vertical anisotropy exacerbates neural deficits, Relumino's MTF reduction paradoxically enhances visual comfort. The algorithm may mimic natural cortical compensation mechanisms by redistributing spatial frequencies and reducing inter-meridian contrast imbalance. Similar neuroadaptive principles are observed in amblyopia therapy, where prolonged deprivation prompts the brain to prioritize clearer signals. Thus, Relumino's efficacy likely extends beyond optical enhancement to neural recalibration, alleviating maladaptive cortical filtering strategies entrenched by uncorrected astigmatism[33]. Despite these benefits, overall patient assessments of Relumino mode remained neutral, suggesting its utility is most pronounced in subgroups with significant meridional anisotropy.

There are several limitations in our study. First, the sample size (N = 38) is quite limited, making it insufficient to generalize the findings across various amblyopic patients. Additionally, patients of different ages may experience varying degrees of visual discomfort, with most children undergoing treatment while adults do not. Therefore, classification testing based on age and treatment status is recommended. Second, it is challenging to quantify visual function objectively. We could not measure binocular contrast sensitivity or stereopsis under the two modes, necessitating other objective measurements to provide complementary information about symptoms of binocular imbalance. Furthermore, the comparison between the two modes in our study was immediate, which might bias participants towards the normal mode due to habitual usage. A more comprehensive assessment could be obtained if participants used the Relumino mode for a week, allowing them to evaluate whether it alleviates amblyopic symptoms such as glare and asthenopia. Lastly, while spatial frequency variations play a key role in improving binocular deficits in amblyopic patients, further exploration is needed to integrate this with screen technology.

Conclusions

In conclusion, our study shows that the Relumino mode can significantly assist amblyopic patients in watching television. Amblyopic patients often endure poor vision and various symptoms throughout their lives. Therefore, it is worthwhile for adults with severe amblyopia to use and evaluate the Relumino mode. In this information age, amblyopic patients rely heavily on screens from smartphones, computers, and televisions. While text clarity may still need improvement and the mode requires further refinement, it has potential for application across various electronic devices. This could reduce the burden on amblyopic patients when using electronic screens and could be integrated with devices used in digital amblyopia treatment.

Methods

Participants

This study was approved by the Human Research Ethics Committee of the Second Affiliated Hospital of Zhejiang University School of Medicine, and it adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants before examination. We recruited participants with amblyopia who met the criteria and had them alternately use the normal mode and the Relumino Mode. This allowed us to test the impact of both modes on the visual function of amblyopic patients.

A total of 38 amblyopic patients participated in this study who attended the Eye Center of the Second Affiliated Hospital of Zhejiang University School of Medicine between October and December 2023 were enrolled in the study (Table1). The criteria for participants are as follows: (1) Aged above 4 years old and diagnosed with anisometropic amblyopia (the best-corrected VA of the worse eye less than 0.2 LogMAR). (2) The eyes do not have obvious strabismus (>4 prism degrees, using Prism and Alternate Cover Test) or congenital cataracts, congenital ptosis and other organic eye diseases and related surgical history (3) At the time of the study, there was no case of photophobia and tearing in any eye due to keratitis, conjunctivitis and other diseases.

Data were obtained from each subject unless he/she did not meet the enrollment criteria. 38 participants cooperated to complete all the study protocol, so the total number of effective participants is 38.

Detecting MTF for two modes

We use MTF to measure the spatial frequency performance of television displays under two different modes. First, we use professional instruments (VESA FPDM 303-7 RESOLUTION FROM CONTRAST MODULATION) to detect the horizontal and vertical grills under two modes. The mean luminance value of the white grill (Lw) and the black grill (Lb) under 1–4 pairs of black and white grills is obtained at 10 random tests on the display. Then, the MTF value is obtained through the formula $MTF = (Lw—Lb) / (Lw + Lb)$.

Detection of visual correlational changes in two modes

The process of verifying the effectiveness of Relumino Mode for improving Visual Functions was undertaken in the following three phases:

Phase 1. After enrolling the participants, we confirmed their information about medical history, degree of amblyopia, and the worse VA eye. Then we did some examinations to record the visual function of participants, including Uncorrected Distance visual acuity (UCVA), Best Corrected Distance Visual Acuity (BCVA), Objective refraction, Manifest refraction, Intraocular pressure (IOP), and stereoacuity (RANDOT® STEREO TEST, USA). In addition, fundus photography and slit lamp examination were conducted to avoid visual functional defects caused by the abnormalities in fundus and anterior segment.

Phase 2. We connected computer to television (Samsung KQ65QNC90AFXKR 65-inch Neo QLED 4 K TV, Korea) and projected electronic visual acuity chart software (Standardized Visual Acuity Chart), short text with scrambled order of words, and three types of 5-min videos (a. animation; b. realistic documentary; c. character-driven film) on television screen.

Phase 3. For the single-use evaluation, we did some examinations immediately before and after use Relumino mode. The sequence of the examinations is as follows:

1. Participants sit 5 m in front of the television to test the best-corrected visual acuity when wearing glasses (Monocular detection).
2. Participants sit 2.3 m in front of the television (the most suitable distance for viewing a 65-inch television), then read scrambled text composed of age-appropriate Chinese characters, selected based on preschool literacy benchmarks. For participants aged < 7, a pre-test validation of character recognition was mandatory; only those demonstrating familiarity with the target characters proceeded to the task. Reading time and accuracy rates were systematically recorded to quantify performance. (Binocular detection)
3. Participants sit 2.3 m in front of the television and sequentially watch three 5-min videos. Each video should be viewed in both modes (normal and Relumino mode).

Development and psychometric evaluation of the VFEQ

After watching the video, all participants completed the Visual Function Evaluation Questionnaire (VFEQ), designed through iterative consultations with screen design experts, clinicians, and patient interviews. The VFEQ assessed five domains: static image clarity, text readability, video quality, subtitle legibility, and overall mode evaluation. For children under 7 years, trained staff administered the questionnaire orally to ensure comprehension.

Reliability and Validity of the VFEQ:

1. Questionnaire Reliability: The reliability was analyzed and determined using Cronbach's alpha coefficient. Cronbach's alpha was considered good because all items had an alpha of more than 0.70, and ours was 0.786 for the total score. Therefore, this questionnaire meets the requirements and can reflect the subject's subjective attitude towards improving visual function in this Relumino mode from a partial perspective.
2. Questionnaire Validity: Data factorability was determined by a Kaiser–Meyer–Olkin (KMO) test value greater than 0.50 and significance of Bartlett's test of sphericity value ($p < 0.05$)[34]. The KMO value of this questionnaire is 0.651. The significance of Bartlett's test of sphericity value is 0.0001 ($p < 0.05$), which means it is valuable to conduct a factor analysis for the given data or the sampling adequacy. Once factorability was confirmed, we used the component matrix after rotation to analyze data that provides validity tests in different dimensions. After that, we can divide all questions into 5 dimensions: static images, text, video, subtitles on TV, and overall evaluation to analyze this questionnaire.

Responses were analyzed to determine the effectiveness of the new mode in enhancing visual functions.

Statistical analysis

We used the SPSS statistical software package version 25 (SPSS Inc., Chicago, IL, USA) for statistical analyses. Data are presented as means ± *SD*. Changes in VA and reading speed/ accuracy rate before and after using Relumino mode were analyzed with Paired-samples T Test and one-sample t-test. In contrast, the reliability and validity of the questionnaire were assessed with Cronbach's alpha coefficient and the Kaiser–Meyer–Olkin (KMO) test. After that, we employed independent samples T-test, Analysis of Variance (ANOVA), and Correlation Analysis for further questionnaire analysis. A p value of < 0.05 was considered statistically significant.

Data availability

Due to privacy and ethical considerations, some data may not be publicly available, but the corresponding author can provide the supporting data upon reasonable request.

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Author contributions

X.J and J.Y designed the project. Y.S, X.Z, J.C were each responsible for specific testing tasks and obtained the data. X.J and J.Y, H.S conducted data statistical analysis. All authors were involved in writing the manuscript and revising.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics statement

This study was approved by the Human Research Ethics Committee of the Second Affiliated Hospital of Zhejiang University School of Medicine (IR2023411), and it adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants before examination. Especially for research involving minor participants (including tissue sample donors), informed consent has been obtained from the parents and/or legal guardians.

Additional information

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