Developing Virtual Reality Mini-Games for Myopia Prevention Habit Training in Chinese Primary School Children: Design, Implementation, and Pilot Evaluation

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DOI: https://doi.org/10.51244/IJRSI.2026.1313CS011

Received: 23 May 2026; Accepted: 28 May 2026; Published: 18 June 2026

ABSTRACT

China is facing a major childhood myopia crisis, with over 53% of school-aged children affected and nearly 92% at the university level. Current school-based programs, especially the required 眼保健操 eye exercise initiative, often struggle with low compliance. This is due to a lack of interactive feedback and rewards. This paper discusses the design, implementation, and initial evaluation of Eye Guardian, a virtual reality (VR) game system featuring three 60-second mini-games: Dragon Chase (which focuses from near to far), Blink Rain (which promotes regular blinking), and Cloud Valley (which provides structured visual breaks). Each mini-game includes a recognized behavior for preventing myopia, presented in a culturally relevant way for Chinese primary school children aged 6 to 12. The prototype was created using Unity 2022 LTS on the Meta Quest 3 standalone headset. It offers bilingual Chinese–English interfaces, incorporates traditional Chinese architectural designs, and uses a unified system for tracking behavior. The pilot evaluation involved 10 participants for the System Usability Scale and 13 for the behavioral intent survey. It resulted in an average System Usability Scale score of 77.5 (SD = 19.5), which falls within the "Good" usability range. Behavioral intent ratings were above 4.0 out of 5.0 across various areas, with cultural relevance scoring the highest consensus (M = 4.69). Gameplay log analysis from 23 internal testing sessions showed reliable data capture. It also indicated a learning effect in Dragon Chase and Blink Rain. To our knowledge, this is the first VR serious game system specifically designed for myopia prevention rather than treatment in Chinese primary school children. The findings suggest that culturally relevant, game-based technologies for eye health can effectively support existing school health programs.

Keywords: myopia prevention; virtual reality; serious games; children; eye health; gamification; China; HCI

INTRODUCTION

Myopia has become one of the most urgent public health issues of the 21st century, especially in East Asia. China is experiencing the worst myopia epidemic in the world, with around 53.6% of school-aged children affected, and this number jumps to over 91.8% among university students. The COVID-19 pandemic has only worsened the situation. Prolonged indoor confinement, increased screen time, and less outdoor activity have created ideal conditions for myopia to develop and worsen. The long-term effects are serious, as high myopia is closely linked to sight-threatening issues like retinal detachment, myopic maculopathy, and glaucoma.

In response, the Chinese government published national myopia prevention guidelines in 2021, setting clear reduction targets to achieve by 2030. Schools in China are required to include the 眼保健操 (eye exercise program), first introduced in the 1960s, as part of their daily routines. Despite these efforts, myopia rates keep rising. This is mainly because passive, instruction-based interventions do not provide the interactive feedback and motivation needed to encourage consistent practice, especially among younger children.

Three behaviors are most strongly supported by clinical evidence as protective against myopia progression: alternating between near and far focus (to exercise accommodative flexibility), frequent blinking (to prevent eye dryness and lessen the demand of close work), and structured visual breaks (to reduce eye muscle fatigue). The biggest challenge in effective prevention is not a lack of understanding about these practices but the ongoing struggle to apply them consistently.

Virtual reality (VR) offers a promising approach to supporting habit formation. It can hold attention in fully controllable environments, allows precise multisensory feedback, and, when paired with game elements, can make repetitive exercises enjoyable for children. However, current VR eye training systems are primarily designed for the clinical treatment of conditions such as strabismus, amblyopia, and low visual acuity, rather than for prevention. Moreover, none is tailored for Chinese primary school children.

This paper introduces Eye Guardian, a VR serious game system that includes three mini-games. These games incorporate the three clinically recognized preventive behaviors within culturally relevant, age-appropriate gameplay for Chinese primary school students. Our contributions are threefold: first, we present the first VR serious game system explicitly designed for myopia prevention rather than treatment; second, we offer a design that reflects the Chinese language and traditional aesthetics and aligns with the national curriculum; and third, we provide an integrated logging system for structured empirical evaluation. We discuss the system design, technical implementation, and results from a pilot usability and behavioral intent evaluation.

RELATED WORK

Epidemiology and Behavioral Interventions

Pan et al. [4] conducted a systematic review and meta-analysis of 82 studies with over 218,000 participants. They found a steady increase in childhood myopia rates in China, with projections indicating near-universal prevalence among urban secondary students by 2050. Wang et al. [12] confirmed, in a longitudinal study involving 4,741 students in Guangzhou who were followed from primary through junior high school, that the yearly incidence of myopia peaks during the early primary years. They noted that children who develop myopia early tend to progress to much higher levels of refractive error. This highlights the need for early intervention during primary school. The COVID-19 pandemic accelerated this trend. Population-based studies across China reported significant rises in myopia incidence during the pandemic, especially among younger children facing longer indoor confinement and increased screen time [13].

Among behavioral interventions, more outdoor activity has the strongest evidence. He et al. [6] conducted a cluster-randomized trial (n = 1,903) that showed that an extra hour of outdoor school activity per day reduced the three-year cumulative incidence of myopia by 23%. This effect is due to greater natural light stimulating retinal dopamine release and preventing axial elongation. The 20-20-20 rule offers some relief from digital eye strain, although evidence on its impact on refractive progression is limited [7]. Chinese eye exercises (眼保健操), while almost universally implemented in schools, show mixed clinical effects in meta-analyses. Compliance quality is a major limiting factor [5].

Serious Games and VR in Pediatric Eye Health

Damaševičius et al. [14] conducted a meta-review of 53 systematic reviews on serious games and gamification in healthcare. They confirmed consistent motivational benefits across age groups but noted significant gaps in standardization, long-term evaluation, and integration into formal health systems. Heldal et al. [15] showed that game-based versions of clinical vision training exercises greatly boost children's motivation to participate compared to passive instruction. Ali et al. [16] found that serious games with eye-tracking can monitor and adjust to individual performance in real time. This feature is a major advantage over static behavioral interventions.

In the VR field, Chan et al. [10] reviewed VR-based platforms for the treatment of amblyopia, strabismus, and myopia. They found that VR's customizable environments allow precise delivery of exercises tailored to individual needs. Kim and Oh [17] demonstrated that VR gameplay can effectively encourage therapeutic eye movement patterns in strabismus rehabilitation, establishing game-based visual training as clinically valid. Brata et al. [18] showed that VR-delivered eye exercises (Bates method) are technically feasible and well-received by users. However, all existing VR eye training systems discussed in the literature follow a treatment-first approach that focuses on diagnosed conditions rather than on healthy children at risk. None is specifically designed for Chinese primary school children.

System Design

Design Principles

Eye Guardian was developed based on three main principles. First, clinical relevance required that each game mechanic directly relate to a behavior supported by myopia prevention studies. Second, child-centered engagement required that all design, visuals, and feedback be tailored to schoolchildren aged 6 to 12. This favored single-button inputs, immediate visual rewards, and minimal on-screen text. Lastly, cultural appropriateness required aesthetic and narrative choices that would appeal to Chinese primary school children. This is reflected in bilingual Chinese–English interfaces, traditional Chinese architectural settings, and culturally relevant narrative elements, such as a dragon character and a cloud valley landscape.

Mini-Game Descriptions

Dragon Chase (near-far focus alternation): A 3D dragon character moves between a near position (Z = 3 units, about reading distance) and a far position (Z = 8 units, representing a meaningful indoor focal target). The child must watch the dragon and press the controller trigger right when it reaches its farthest point. This mechanism works the ciliary muscle through repeated focusing and relaxing, simulating the recommendation to shift gaze to a distant object during close work. The scene avoids complex peripheral visuals to reduce the demand for accommodation beyond the near-far focus.

Blink Rain (regular blinking): Rain falls continuously in the VR environment, growing stronger as the child forgets to blink. Pressing the controller button simulates a blink, immediately clearing the rain and fog while providing strong positive visual feedback. The darkness accumulation mechanic creates a feedback loop based on clinical data. The warning state begins roughly 8–10 seconds after neglecting to blink, in line with studies showing that blink rate during screen use drops to 4–6 blinks per minute. The target blink count of 10–14 in a 60-second session matches the recommended rate of 12–15 blinks per minute.

Cloud Valley (structured visual rest and breathing): A peaceful valley environment features an expanding and contracting visual circle that guides the child through a suggested 8-second breathing cycle (4 seconds inhale, 4 seconds exhale). The game requires no active controller input—the automatic breathing cycle results in a consistent score of 7 completed cycles per 60-second session. This ensures meaningful engagement through passive guided practice. This game also serves as a break between the more mentally demanding Dragon Chase and Blink Rain sessions, in line with cognitive load theory, which suggests alternating high- and low-demand tasks within training sessions.

Technical Implementation

Development Environment

The prototype was developed using Unity 2022 LTS, selected for its long-term support stability and comprehensive VR development ecosystem. The target hardware platform is the Meta Quest 3 standalone headset, which provides fully self-contained VR capability without requiring a tethered PC or external tracking sensors, making it suitable for school deployment without dedicated computing infrastructure. The XR Interaction Toolkit and Oculus Integration SDK were integrated for standardized cross-platform input handling and reliable Meta Quest compatibility. All scripting was implemented in C# using Visual Studio, with Git for version control.

Key Implementation Decisions

Chinese language rendering was the most technically demanding implementation challenge. Default TextMesh Pro font assets lacked the CJK character range, resulting in empty replacement boxes. This was resolved by regenerating font assets using the TextMesh Pro Font Asset Creator with Character Sequence covering the full CJK Unified Ideographs block (decimal range 19968–40959) and fullwidth punctuation range (65281–65374), at an atlas resolution of 4096 × 4096, producing a complete 20,992-character CJK font atlas with zero missing or excluded characters.

The Blink Rain feedback system uses Unity's Mathf. Lerp function to interpolate rain emission rate (30f–200f), particle start speed (4f–8f), and exponential-squared fog density (0–0.08) continuously against a darkness accumulation variable (rate: 0.08f per frame), producing naturalistic gradual escalation rather than stepped thresholds. Upon blink input, all three visual parameters reset simultaneously to baseline, providing dramatically visible positive reinforcement. The Cloud Valley breathing animation uses normalized interpolation (t = breathTimer / breathDuration) to drive the circle's scale between 0.5 and 1.5, ensuring perfect synchronization between the visual animation and the bilingual instructional text throughout the full session without drift.

Session data is transferred between Unity scenes using PlayerPrefs (FinalScore, GameType, GameDuration) and written to a unified GameLogs.csv file at Application.persistentDataPath. The CSV captures six fields per session: timestamp, game type, score, score label (Score / Blinks / Breath cycles), duration in seconds, and device identifier. This design enables cross-game analysis without data merging and supports export via Android Debug Bridge for analysis in Microsoft Excel.

Evaluation

Study Design and Participants

Evaluation was structured in two phases. Phase 1 comprised 23 internal gameplay sessions across multiple dates (March 5–April 20, 2026), covering 8 sessions of Dragon Chase, 8 of Blink Rain, and 7 of Cloud Valley, to verify the logging system's reliability and establish baseline performance benchmarks. Phase 2 comprised external evaluation with proxy participants: the System Usability Scale (SUS) was completed by n = 10 participants, and a custom 20-item Behavioral Intent and Engagement Survey was completed by n = 13 participants. Participant demographics for the survey sample were: 85% aged 18–25, 15% under 18; 77% female, 23% male; 62% with prior VR experience; 31% working with children regularly or having children of their own. Evaluation was conducted with university-age proxy participants, consistent with established HCI practice for proof-of-concept systems, as formal child testing requires ethical approval and institutional school access, which are beyond the scope of this project.

Instruments

The System Usability Scale (SUS) [19] is a validated 10-item questionnaire that produces composite scores ranging from 0 to 100 (scores > 68 = acceptable; > 80 = good; > 90 = excellent). The custom Behavioral Intent and Engagement Survey comprised 20 Likert-scale items (1–5) organized across three sections: Perceived Relevance (4 items), Perceived Engagement (8 items), and Behavioral Intent (4 items), supplemented by two open-ended qualitative questions. The GameLogs.csv automated logging system served as the primary data source for the objective, capturing structured session records without manual input.

Gameplay Log Results

Game	Sessions (n)	Metric	Min	Max	Mean (SD)
Dragon Chase	8	Score (points)	1	14	9.25 (4.2)
Blink Rain	8	Blinks	5	14	10.5 (3.1)
Cloud Valley	7	Breath cycles	7	7	7.0 (0.0)

Table 1. Descriptive statistics for gameplay sessions across three mini-games (n = 23 sessions).

All 23 sessions recorded an identical duration of 60 seconds, confirming correct session timer operation across all games and testing dates. Dragon Chase exhibited a clear learning trajectory: scores rose from a mean of 4.0

across the first two sessions (including one likely calibration error that produced a score of 1) to a mean of 11.0 across sessions 3–8, representing a 175% improvement. Blink Rain showed similar progression, from 5–7 blinks in early sessions to a consistent plateau of 12–14 blinks. The upper range of sessions 3–8 falls within the clinically recommended rate of 12–15 blinks per minute. Cloud Valley's perfectly consistent score of 7.0 across all sessions reflects the deterministic timer-driven breathing mechanic (theoretical maximum: 7.5 complete cycles per 60 seconds at 4s per phase).

SUS Results

Participant	**SUS Score**	**Usability Band**
P1	100.0	Excellent
P2	82.5	Good
P3	87.5	Good
P4	87.5	Good
P5	50.0	Poor
P6	52.5	Poor
P7	47.5	Poor
P8	90.0	Excellent
P9	90.0	Excellent
P10	87.5	Good
Mean (SD)	77.5 (19.5)	Good

Table 2. Individual and mean SUS scores (n = 10).

The mean SUS score of 77.5 (SD = 19.5) falls within the "Good" usability band, exceeding the widely cited acceptable threshold of 68. Seven of ten participants scored above the acceptable threshold. The three achieved scores of 90 or above. The high standard deviation reflects genuine variation attributable to diverse prior VR experience levels in the sample, with the three lowest scorers (P5–P7) all reporting no prior VR exposure.

Behavioral Intent and Engagement Survey

Section / Item	**Mean**	**SD**
A. Perceived Relevance		
Behaviors relevant to eye health	4.46	0.88
System could help children develop healthier habits	4.15	1.07
60-second session length appropriate	4.15	1.07
Gamification more effective than passive exercises	4.00	1.22
Section A Mean	4.19	

B. Perceived Engagement		
Visual design engaging for children 6–12	4.08	1.04
Dragon Chase motivates focus shifting	4.46	1.13
Bilingual interface appropriate	4.69	0.48
Dragon character culturally relevant	4.69	0.48
Blink Rain raises blinking awareness	4.46	0.52
Rain/fog feedback communicates consequence	4.00	1.00
Cloud Valley helps children relax	4.38	0.51
Breathing circle easy to follow	4.31	1.11
Section B Mean	4.38	
C. Behavioral Intent		
Children would use it regularly in schools	4.23	0.83
Would recommend for primary schools	4.38	0.87
Gamification effective for health education	4.46	0.88
Parents comfortable allowing VR use	4.31	0.85
Section C Mean	4.35	

Table 3. Behavioral Intent and Engagement Survey results (n = 13).

All three survey sections produced mean scores exceeding 4.0/5.0, indicating consistently positive perceptions of relevance, engagement, and behavioral intent. The two highest-rated items were with a bilingual interface and the dragon character's cultural relevance (both M = 4.69, SD = 0.48). All achieved the strongest consensus across the sample, validating the design decision to ground the system in Chinese cultural aesthetics and bilingual communication. The lowest-rated item (rain/fog feedback clarity in Blink Rain, M = 4.00, SD = 1.00) identifies a specific element warranting refinement in future iterations.

Qualitative Findings

Thematic analysis of open-ended responses yielded three recurring themes. VR safety and duration concerns were raised by multiple participants, who noted the importance of supervised use and session length limits for young children. These concerns are addressed by the 60-second session structure. Positive perceptions of innovation and cultural relevance were widespread, with participants describing the system as "creative," "innovative," and "engaging," specifically highlighting the bilingual interface and dragon character as appropriate and appealing. Suggestions for future development included parental/teacher monitoring features, expansion of culturally relevant game content, and longitudinal effectiveness studies, all of which align directly with the research directions identified in Section 6.

DISCUSSION

The mean SUS score of 77.5 provides preliminary evidence that the Eye Guardian prototype achieves good usability as a VR application, even for participants without prior VR experience. The high consensus around cultural relevance and bilingual interface design (M = 4.69) validates the design hypothesis that cultural specificity is functionally important—not merely decorative—for engagement and perceived appropriateness in health technology targeting Chinese children. This aligns with the broader argument that culturally neutral digital health tools developed in Western contexts may achieve lower adoption in Chinese educational settings, even when the underlying clinical goals are identical.

The learning effect observed in Dragon Chase (mean scores rising from 4.0 to 11.0 across sessions) and Blink Rain (5–7 blinks in early sessions rising to a plateau of 12–14) provides preliminary behavioral evidence consistent with habit formation: participants not only engaged with the mechanic but improved their alignment with the therapeutic target over time. The Blink Rain plateau of 12–14 blinks per session falls within the clinically recommended range of 12–15 blinks per minute, suggesting that the operant conditioning mechanism successfully trains blinking at a therapeutically relevant frequency. Cloud Valley's perfectly consistent score of 7 breath cycles across all sessions confirms reliable delivery of the structured breathing exercise.

Several limitations must be acknowledged. Most critically, evaluation was conducted with university-age proxy participants rather than the intended target population of children aged 6–12, meaning developmental appropriateness cannot be confirmed from current data. The controller-press proxy for blinking and focus shifting measures behavioral intent rather than physiological behavior, a gap that eye-tracking integration would address. The evaluation sample was small (n = 10–13) and conducted without longitudinal follow-up, precluding assessment of sustained habit formation. Finally, cultural relevance was informed by design literature rather than empirically validated with Chinese children and families.

Comparison with existing systems highlights the novelty of this contribution. Kim and Oh [17], Kawamori and Imura [20], and Lv et al. [21] all target diagnosed visual conditions in treatment settings, rather than healthy at-risk children in prevention contexts. No existing VR eye training system reviewed in the literature incorporates Chinese cultural aesthetics, bilingual CJK interfaces, or alignment with China's national myopia prevention curriculum, which are gaps that Eye Guardian directly addresses.

CONCLUSIONS AND FUTURE WORK

This paper introduces Eye Guardian, a VR serious game prototype that, to our knowledge, is the first system designed specifically to prevent myopia in Chinese primary school children through behavioral habit training, rather than treating existing visual conditions. The prototype demonstrates technical feasibility by integrating culturally grounded design, bilingual Chinese–English interfaces, three clinically motivated mini-games, and a unified behavioral logging system. A pilot evaluation yielded a mean SUS score of 77.5 (indicating good usability), behavioral intent ratings consistently above 4.0 out of 5.0, and gameplay logs that reflect learning effects consistent with habit formation.

Future work will proceed in four directions. First, a controlled usability study with Chinese primary school children aged 6–12 in a real school setting, with parental consent and ethical approval, will provide the first direct empirical evidence of the system's effectiveness with its target audience. Second, integrating affordable eye-tracking hardware, such as the Meta Quest Pro's built-in eye-tracking, will replace the controller-press proxy with physiological measurement. This will transform the prototype into a true behavioral measurement tool and significantly increase the scientific validity of future evaluations. Third, an adaptive difficulty system will adjust dragon movement speed in Dragon Chase and darkness accumulation rate in Blink Rain based on individual performance. The behavioral logging infrastructure will also be expanded to capture per-event reaction times, inter-blink intervals, and breathing rhythm accuracy, aligning the system more closely with the personalized training model demonstrated by Ali et al. [16]. Finally, a longitudinal evaluation will measure blink frequency, near-work habits, and optometric outcomes, including axial length and refractive error, at baseline and follow-up, before and after four to eight weeks of daily system use. This will provide the clinical outcome evidence that the current proof-of-concept cannot offer.

Looking ahead, the connected logging infrastructure in this prototype enables the development of a three-tier health monitoring ecosystem. Behavioral data from daily gameplay could be shared with parents through a companion monitoring interface and with ophthalmologists during clinical appointments. This approach would bridge the gap between home-based preventive practice and clinical oversight, supporting more informed and timely interventions. It positions VR serious games as active components of a child's clinical care pathway, not just as educational tools.

This work demonstrates that VR can provide a culturally appropriate, engaging, and measurable platform for myopia prevention habit training in the population most at risk. It opens a new direction for pediatric health technology that prioritizes prevention over treatment, cultural specificity over neutrality, and engagement over compliance. This approach has meaningful implications for the millions of Chinese children whose visual futures depend on making prevention a daily habit.

Author Contributions: Conceptualization, B.Doha.; methodology, B.Doha; software, B.Doha; formal analysis, B.Doha; writing,review and editing, B.Doha; supervision, J. Taiping. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with established HCI research practice for proof-of-concept prototype evaluation with adult proxy participants. Child-centered trials in future work will require formal IRB approval.

Informed Consent Statement: The survey was conducted anonymously. No personal identifying information was collected from participants. Participants were informed of the voluntary and anonymous nature of the study prior to completing the questionnaire.

Data Availability Statement: The GameLogs.csv dataset supporting the reported statistics is available from the corresponding author upon reasonable request.

Conflicts of Interest: The author declares no conflict of interest.

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