



VisionCare: A Closed-Loop Digital Health System for Eye Health and Screen-Time Management in Children with ADHD

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ARTICLE INFO

Article history:

Received 26 July 2026

Received in revised form 30 September 2026

Accepted 30 September 2026

Available online 9 October 2026

Keywords:

ADHD; digital health; eye-tracking;
machine learning; screen-time
management

ABSTRACT

Attention-deficit/hyperactivity disorder can make self-regulation of digital device use difficult, while prolonged screen exposure may contribute to visual discomfort and fatigue. Existing digital tools commonly address behavioural management or eye health separately, leaving a gap in integrated, real-time support. This study aimed to design and pilot-test VisionCare, a closed-loop digital health system combining real-time eye monitoring with adaptive screen-time support for children with attention-deficit/hyperactivity disorder. The system was developed using user-centered design and iterative Agile methods. OpenCV and TensorFlow Lite processed front-camera video for gaze and blink monitoring, while a Support Vector Machine classifier used gaze, blink, and application-interaction features to identify disengagement or fatigue states and trigger break prompts. A two-week home pilot involved ten child-caregiver dyads. Technical performance, daily screen time, break-prompt compliance, caregiver-reported outcomes, and System Usability Scale scores were assessed. The eye-tracking module reported 92% detection accuracy, and the classifier achieved an F1-score of 0.89. Daily screen time decreased by an average of 28%; caregivers reported improved break-prompt compliance and fewer eye-strain complaints; and the mean usability score exceeded 80/100. The findings indicate preliminary feasibility and usability, but the small convenience sample, short duration, and incomplete model-validation details require confirmation in larger longitudinal studies.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a prevalent neurodevelopmental condition characterized by persistent patterns of inattention, hyperactivity, and impulsivity that can interfere with learning, family routines, and everyday functioning [1,2]. Digital environments can intensify self-regulatory demands because device use requires sustained attention, planned task switching, and voluntary disengagement. For children with ADHD, these demands may contribute to prolonged or poorly regulated screen use, while extended viewing may coincide with symptoms associated with digital eye strain, including ocular discomfort, headaches, blurred vision, and reduced blink behaviour [3,17].

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Digital health interventions have increasingly been investigated as adjuncts for ADHD-related support. Mapping and meta-analytic reviews describe interventions delivered through mobile health applications, telehealth, serious games, web-based platforms, and other digital modalities [3-6]. Specific studies have explored medication reminders [7], wearable-supported physical activity [8], personalized mobile exercise programs [9], and web-based teacher support [10]. These approaches demonstrate that digital technologies can support different behavioural, educational, and health-management needs, but the intervention landscape remains heterogeneous, and the evidence base is uneven across products and contexts [3,6].

A further concern is the gap between promising prototypes and empirically supported tools used in everyday settings. Reviews of ADHD mobile applications report that many commercial products have limited empirical support, inconsistent clinical grounding, or narrow functionality [11]. Ability-based design emphasizes designing around users' capabilities rather than treating individual differences as deficits [12], while gamified and interactive systems have been explored as mechanisms for improving engagement among users with ADHD [13]. Eye-tracking has also been investigated as an assistive modality for cognitive support in children with ADHD [14], and ambulatory assessment research highlights the potential of just-in-time adaptive interventions that respond to changing states in naturalistic environments [16].

The principal research gap is therefore not the absence of digital ADHD interventions, but the limited integration of behavioural self-regulation support with real-time physiological monitoring of screen-related visual strain. Existing approaches commonly address symptom management, activity, medication adherence, or screen control as separate concerns [3,7-11]. An integrated closed-loop system could be significant because it would allow device-use boundaries and visual-health prompts to respond to a child's current interaction pattern rather than relying only on static schedules or parental enforcement. Accordingly, the objective of this study was to design and pilot-evaluate VisionCare, a personalized system that combines computer-vision eye monitoring, machine-learning-based attention classification, adaptive break prompts, and caregiver oversight for children with ADHD in the home environment.

2. Methodology

2.1 Research Design and Development Approach

VisionCare was developed using a User-Centered Design approach supported by iterative Agile and Scrum practices. The development process comprised four stages: requirements analysis, interface and interaction design, system implementation, and testing. During requirements analysis, the manuscript reports semi-structured input from caregivers, educators, and paediatric specialists to identify needs such as real-time screen-time monitoring, parental notifications, and interactive break reminders.

The design stage used Figma to produce low- and high-fidelity wireframes, with emphasis on child-friendly, non-stigmatizing interfaces, high visual contrast, and simple navigation. This orientation is consistent with ability-based design principles, which prioritize adaptation to users' abilities and interaction needs [12]. The implementation stage used Flutter for cross-platform mobile development, with Firebase and Google Cloud Functions supporting authentication, cloud storage, and real-time analytics. Unit, integration, and system testing were subsequently used to assess software stability, cross-platform compatibility, and data-processing behaviour.

2.2 VisionCare System Architecture and Adaptive Intervention

The VisionCare architecture comprises two principal computational modules. The first is an eye-monitoring module implemented using OpenCV and TensorFlow Lite. Front-camera video streams are processed to monitor gaze position, blink behaviour, and estimated screen-to-eye distance. The second is an adaptive feedback engine based on a Support Vector Machine (SVM) classifier. The classifier uses gaze position, inter-blink behaviour, and application-interaction telemetry to identify patterns interpreted by the system as disengagement or fatigue. When a target state is detected, the application activates localized prompts, gamified eye exercises, or break reminders. The design therefore follows a closed-loop logic in which sensed behaviour informs classification and classification triggers a user-facing intervention, rather than relying only on fixed screen-time limits. Table 1 summarizes the main development and pilot-evaluation components reported in the manuscript.

Table 1
Summary of VisionCare development and pilot evaluation

Component	Study specification
Development approach	User-Centered Design with iterative Agile and Scrum practices
Mobile implementation	Flutter for cross-platform application development
Cloud services	Firebase and Google Cloud Functions for authentication, storage, and analytics
Eye-monitoring module	OpenCV and TensorFlow Lite; gaze, blink behaviour, and screen-to-eye distance
Adaptive classifier	Support Vector Machine using gaze, blink, and app-interaction features
Pilot sample	10 child-caregiver dyads; convenience sample
Child age range	6-12 years
Deployment setting and duration	Home environment; 2 weeks
Evaluation outcomes	Eye-tracking accuracy; SVM F1-score; daily screen-time change; break-prompt compliance; caregiver feedback; System Usability Scale

2.3 Pilot Participants and Procedure

A two-week pilot evaluation was conducted in the home environment using a convenience sample of ten child-caregiver dyads. Eligible children were reported to be 6-12 years of age and to have a confirmed clinical diagnosis of ADHD based on Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition criteria. Dyads used VisionCare during the child's typical device-use periods. The home setting was selected to examine the system under everyday conditions in which screen-time transitions, caregiver oversight, and competing household activities naturally occur. The source manuscript states that parental consent and child assent were obtained before data collection and that the study followed the ethical principles.

2.4 Measures and Data Analysis

Technical evaluation focused on the operational performance of the eye-monitoring and classification modules. The manuscript reports eye-tracking detection accuracy and SVM F1-score as the principal technical metrics. Behavioural evaluation examined the percentage change in daily screen time and compliance with system-generated break reminders. Caregiver feedback captured perceived changes in eye-strain complaints, task completion, unstructured application switching, ease of use, and the usefulness of parent-facing reports. Perceived usability was measured using the

10-item System Usability Scale (SUS). The source manuscript reports an average score exceeding 80/100 but does not provide the exact mean, standard deviation, range, or participant-level distribution. The reported pilot outcomes were summarized descriptively. Because the manuscript does not report inferential tests, confidence intervals, or a control group, the revised manuscript does not characterize observed changes as statistically significant.

2.5 Data Privacy and Security

The manuscript reports that user authentication and cloud-based analytics were encrypted and that clinical diagnoses and demographic variables were stored using pseudonymized identifiers. These measures were intended to reduce direct exposure of personally identifiable information during cloud processing. For publication, the specific encryption standard, data-retention period, access-control model, storage region, and procedure for deleting participant data should be reported if they formed part of the implemented protocol.

3. Results

3.1 Technical Performance of the Core Modules

The eye-monitoring module was evaluated under varying household lighting conditions to assess its ability to detect prolonged focus episodes and related eye-behaviour patterns. The source manuscript reports a detection accuracy of 92%. This result indicates that the module was able to identify the target eye-monitoring state in most evaluated instances, although interpretation is constrained by the absence of the test-set size, ground-truth procedure, and confusion-matrix data.

The SVM classifier used gaze coordinates, inter-blink information, and application-switching telemetry to classify attention or disengagement states. The reported F1-score was 0.89. This performance supported the use of the classifier as the trigger for adaptive break prompts and eye-exercise reminders during the pilot. Because the source manuscript does not report precision, recall, class balance, cross-validation design, or external validation, the result should be interpreted as preliminary technical performance rather than evidence of generalizable predictive accuracy.

3.2 Screen-Time and Behavioural Outcomes

Across the two-week home deployment, participants showed an average 28% reduction in daily screen time relative to the pre-deployment level reported in the source manuscript. The revised manuscript describes this as an observed average reduction because the underlying baseline and follow-up mean, dispersion measures, and inferential statistics were not reported. Caregiver feedback also indicated improved compliance with system-generated break prompts and eye exercises.

Caregivers further reported fewer complaints associated with visual discomfort, including dry eyes, headaches, and blurred vision during or after device use. Behavioural feedback described improved task completion and reduced impulsive, unstructured application switching when the ADHD assistance mode was active. These outcomes are caregiver-reported observations rather than independently verified clinical endpoints, and no ophthalmic examination or standardized ADHD symptom scale was reported as part of the two-week pilot.

3.3 Usability and Caregiver Feedback

Post-deployment caregiver responses produced an average SUS score above 80/100, indicating high perceived usability in the source manuscript. Caregivers highlighted the separation of parent and child dashboards, the legibility and child-friendly presentation of the interface, and the usefulness of weekly health reports and real-time usage analytics. Qualitative feedback also suggested that automated prompts reduced the need for repeated direct parental enforcement of device boundaries, which caregivers perceived as helpful for managing screen-related conflict. Table 2 consolidates the principal technical, behavioral, and usability outcomes reported in the pilot.

Table 2

Summary of reported VisionCare pilot outcomes

Outcome domain	Reported result	Interpretive caution
Eye-monitoring performance	92% detection accuracy	Test-set size and ground-truth procedure not reported
SVM classification	F1-score = 0.89	Training/test split, class balance, precision, and recall not reported
Daily screen time	Average reduction of 28%	Baseline/follow-up means, variance, and inferential testing not reported
Break-prompt compliance	Caregivers reported improved compliance	No quantitative adherence rate reported
Eye-strain complaints	Caregivers reported fewer dry-eye, headache, and blurred-vision complaints	No objective ophthalmic measure reported
Behavioural self-regulation	Caregivers reported better task completion and less unstructured app switching	Caregiver-reported outcome only
Usability	Average SUS > 80/100	Exact mean, standard deviation, and range not reported

3.4 Interpretation and Implications

The pilot findings support the feasibility of combining physiological interaction monitoring with adaptive behavioural prompts in a single child-focused digital health platform. This integration responds to the fragmentation identified in reviews of digital ADHD interventions, where many systems target cognition, symptom tracking, medication adherence, physical activity, or caregiver support as separate functions [3,6-11]. VisionCare extends this direction by linking sensed eye and interaction behaviour to an immediate system response, thereby moving from passive monitoring toward a closed-loop intervention model.

The design is also consistent with just-in-time adaptive intervention concepts, which emphasize delivering support when a user's state or context indicates that an intervention may be useful [16]. In VisionCare, eye-monitoring and interaction signals function as the state-detection layer, while the feedback engine provides the adaptive response. This approach is conceptually compatible with prior work using interactive and gamified technologies for ADHD [13,14], but the current pilot does not establish superiority over conventional screen-time controls or other digital interventions because no comparator group was included.

From a practical perspective, the observed reduction in daily screen time and high caregiver-rated usability suggest that automation may help shift some device-boundary management from repeated caregiver enforcement to system-mediated prompts. The potential value of this approach lies in supporting both the child and caregiver within the home setting. Future evaluations should

determine whether such support translates into sustained changes in device-use behaviour, validated ADHD-related functioning, visual-health outcomes, and broader health-related quality of life. Existing paediatric ADHD quality-of-life measurement reviews may inform selection of validated outcome instruments for larger studies [15].

3.5 Limitations and Future Work

The study has several limitations. First, the convenience sample comprised only ten child-caregiver dyads and the deployment lasted two weeks, limiting statistical power and long-term interpretation. Second, there was no control or comparison condition, so the 28% screen-time reduction cannot be attributed exclusively to VisionCare. Third, several outcomes were based on caregiver reports, and no standardized ophthalmic examination, objective symptom scale, or independent behavioural observation was reported. Fourth, the manuscript does not provide sufficient technical detail to reproduce the SVM training and validation procedure or the calculation of the 92% eye-monitoring accuracy. Finally, uncontrolled differences in household lighting, device type, camera position, internet connectivity, and caregiver involvement may have influenced system performance and participant behaviour.

Future research should therefore use a larger and more diverse sample, longer follow-up, pre-specified clinical and technical endpoints, and an appropriate comparison condition. External validation should assess performance across device models, lighting conditions, and user characteristics. The evaluation should report full classification metrics, confusion matrices, confidence intervals, and participant-level usability statistics. Longer-term studies should also incorporate validated ADHD functioning and paediatric quality-of-life instruments [15], objective visual-health measures, and clear data-governance documentation. These steps are necessary before claims of clinical efficacy or generalizable effectiveness can be made.

4. Conclusions

This study designed and pilot-evaluated VisionCare, a closed-loop digital health system intended to support screen-time self-regulation and eye-health behaviours among children with ADHD. The system integrates OpenCV and TensorFlow Lite eye monitoring, SVM-based attention-state classification, adaptive break and eye-exercise prompts, caregiver dashboards, and cloud-supported analytics. In the reported two-week home pilot with ten child-caregiver dyads, the eye-monitoring module achieved 92% detection accuracy, the SVM classifier achieved an F1-score of 0.89, daily screen time decreased by an average of 28%, and caregiver-rated usability exceeded 80/100 on the SUS. Caregivers also reported improved compliance with break prompts, fewer eye-strain complaints, and better management of screen-related routines.

These results address the study objective by demonstrating preliminary technical feasibility and high perceived usability of an integrated adaptive approach. The findings should not yet be interpreted as evidence of clinical efficacy because of the small convenience sample, short evaluation period, absence of a comparator, reliance on caregiver-reported outcomes, and incomplete reporting of model-validation details. With stronger experimental design, reproducible machine-learning reporting, objective visual-health measures, and longer-term follow-up, VisionCare could provide a useful framework for evaluating just-in-time, family-cantered digital support for children with ADHD.

Acknowledgement

The authors acknowledge Management and Science University (MSU) for institutional support.

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