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Eyes on the Future: Applications of Eye tracking in pediatric dentistry

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Abstract
Eye tracking technology is a powerful tool for capturing and analyzing visual attention and cognitive processing in real time. In pediatric dentistry—where effective treatment delivery depends not only on clinical skill but also on a profound understanding of child behavior and emotional responses—eye tracking offers novel applications for improving patient care, communication, and dental education. This non-invasive technology provides objective insight into visual engagement, anxiety markers, and operator efficiency. It also aids in optimizing behavior guidance techniques, evaluating distraction tools, enhancing operatory design, and informing ergonomic adjustments for dental teams. Furthermore, eye tracking contributes to training and research by mapping clinician gaze behavior and decision-making during pediatric procedures. This review explores the working principles of eye tracking, its diverse applications in pediatric dental settings, its advantages and limitations, and future possibilities with AI integration and Tele-dentistry expansion

Keywords: Eye tracking, pediatric dentistry, visual attention, behavior guidance, dental education

Introduction

Pediatric dentistry involves more than managing oral diseases. It requires engaging young patients with compassion, interpreting behavioral cues, and ensuring psychological comfort during procedures. Traditional tools for behavior assessment, such as the Frankl scale or parental questionnaires, rely heavily on subjective interpretation and fail to offer real-time or granular insights into child responses during dental care [1]. This limitation has prompted the exploration of digital behavioral analysis tools. Recent advancement among them, eye tracking technology.

Eye tracking captures a subject's gaze path, fixation duration, saccades, and pupil diameter, offering insights into visual attention, decision-making, and emotional arousal [2, 3]. Initially utilized in psychology and marketing, it is now entering healthcare fields, including surgery [4], education [5], and increasingly, dentistry [6]. In pediatric settings, where nonverbal communication dominates, eye tracking can uncover behavioral triggers, measure anxiety objectively, and personalize clinical approaches [7, 8].

At the same time, eye-tracking technology serves as a valuable tool for educators and researchers to analyze the clinical skills, ergonomic behavior, and concentration levels of dental practitioners. [9, 10] as dentistry advances toward data-driven, patient-centered care, eye tracking is emerging as a critical adjunct in understanding and enhancing visual and behavioral dynamics in pediatric dental practice.

Workflow of Eye Tracking in Pediatric Dental Settings

Eye tracking technology has evolved from early methods like Electrooculogram (EOG) and scleral coils to advanced systems using infrared video cameras. These tools help monitor where and how the eyes move, offering valuable insights into attention and behavior.

The process begins with patient preparation, followed by eye tracker setup, using either screen-based or wearable devices. After calibration, gaze data is collected, capturing eye movements like fixations, saccades, and pupil changes.

Next, visual behavior is analyzed to identify focus areas, anxiety triggers, and gaze aversion. This helps guide the clinical response, such as adjusting tools, offering behavior cues, or enhancing distractions. Finally, the gathered data is used for training and research, improving clinician skills, supporting AI development, and enhancing patient care through behavior-based insights. [10]

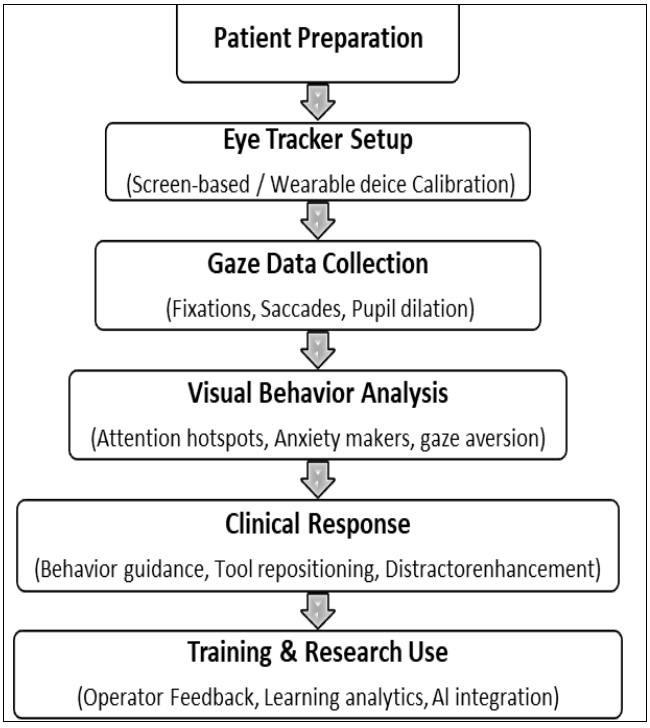

Fig 1: Workflow of Eye Tracking

Basics of Eye Tracking Technology

Modern eye tracking systems utilize infrared light directed toward the cornea and retina. Reflections are recorded by sensors, and algorithms calculate the point of gaze, fixation

duration, saccadic movement, and scan paths [11]. Two major system types exist:

1. Screen-based systems (stationary) for radiograph interpretation or simulation-based training [12].
2. Wearable systems (e.g., glasses) for dynamic, real-time procedures in clinical settings [13].

Table 1-summarizes key eye tracking metrics—such as fixation duration, saccades, pupil dilation, blink rate, and gaze paths—and their application in pediatric dentistry. [14, 15]

Table 1: Summarizes key Eye Tracking Metrics and Their Pediatric Relevance

Metric	Pediatric Relevance
Fixation	Measures the duration of time the gaze remains on a single point: Understanding attention allocation, focus on instructional material and areas of interest during dental examinations or procedures.
Saccade	Analyzing visual search patterns: Transions between regions of interest, and overall visual information processing efficiency.
Pupil Dilation	Indicates psycho physiological responses to anxiety, stress, or cognitive load during dental treatment.
Gaze Duration	Assesses engagement with visual stimuli, comprehension of educational content, and attention to specific dental procedures.
Fixation Count	Evaluates the number of fixations within a specific area. Indicating areas of greater interest or received important.
Blinks	Monitors cognitive and emotional states, as well as comfort. or discomfort levels during dental visits.

Data output takes the form of heatmaps, gaze plots, and Area-of-Interest (AOI) statistics, offering visual representations of attention and emotional engagement [16].

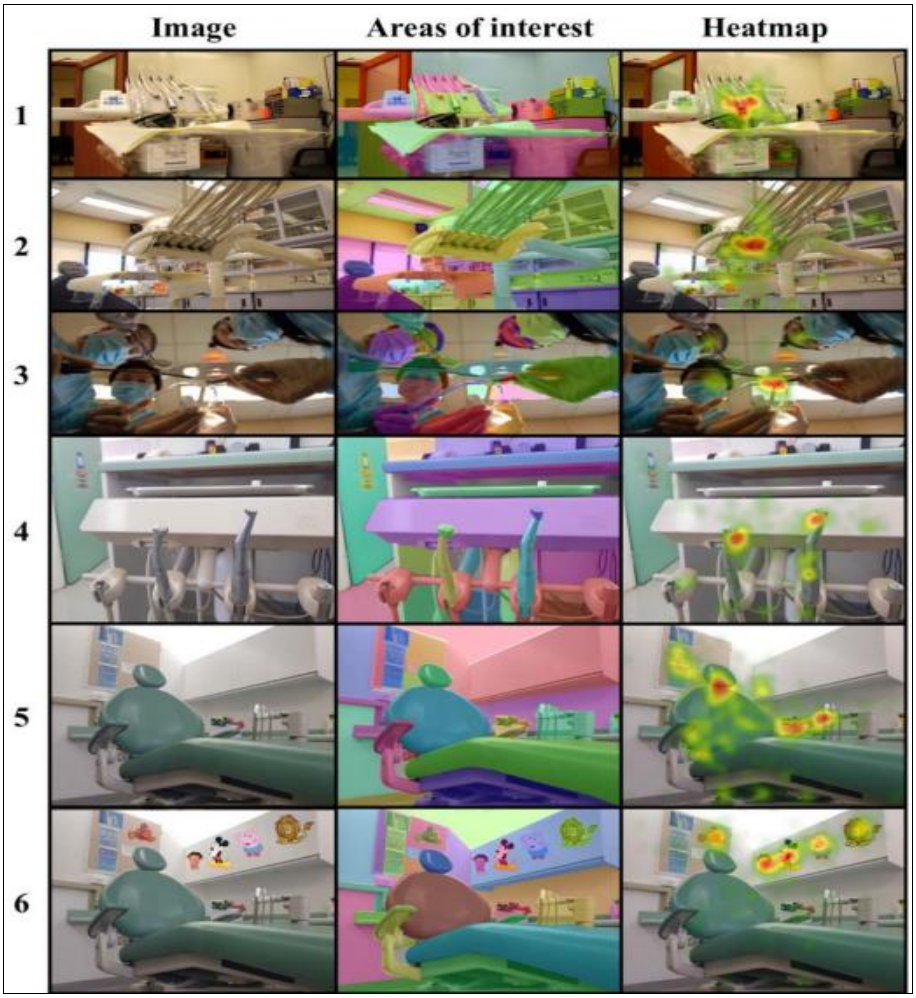

Fig 2: Illustrates typical data output in eye tracking technology, including heatmaps, gaze plots, and Area-of-Interest (AOI) statistics. These visual representations provide insights into children's attention patterns and emotional engagement during dental procedures [16]

Applications in Dentistry

Radiographic and Diagnostic Tasks

Eye tracking reveals differences in visual strategies between novice and experienced clinicians during image interpretation. Experts tend to exhibit fewer, more targeted fixations on diagnostic landmarks, while novices display longer and more scattered gaze paths [17, 18]. Identifying these differences allows educators to design more effective teaching modules.

Dental Education and Training

In simulation-based dental training, eye tracking enables self-assessment and peer comparison. By visualizing one's gaze patterns against those of mentors, students can refine

search efficiency and task sequencing [19, 20]. Eye tracking has also been linked to improved performance in cavity preparation, radiograph reading, ergonomic positioning [21].

Clinical Ergonomics

Ergonomic strain in dentistry is a well-documented occupational hazard. Eye tracking can reveal mismatches between eye movements and posture—prompting redesign of workspace layouts to minimize musculoskeletal burden [22, 23]. It also helps optimize positioning of tools, monitors, and assistants to improve workflow efficiency.

Unique Applications in Pediatric Dentistry

1. Understanding Visual Behavior in Children

Children in dental settings are highly visually reactive. Eye tracking has demonstrated that anxious children tend to fixate on threatening stimuli (e.g., syringes), or avoid gaze altogether [24]. Quantifying this behavior helps clinicians identify anxiety early and implement behavior guidance strategies.

2. Dental Anxiety and Fear Recognition

Dental fear in children manifests through darting gaze, increased blink rate, and avoidance of dental instruments. Eye tracking provides objective, real-time detection of these signs [25, 26]. These data-driven insights allow clinicians to switch to non-threatening language or reposition tools out of the child's line of sight.

3. Evaluating Distraction Techniques

Popular distraction methods include video goggles, ceiling screens, and virtual reality (VR). Eye tracking can validate their effectiveness by measuring sustained fixation and engagement duration [27, 28]. Personalized content—based on a child's interests—results in longer visual engagement, enhancing procedural cooperation [29].

4. Operatory Design Optimization

Studies show that cartoon murals, indirect lighting, and concealment of instruments lead to calming gaze patterns and higher compliance [30]. Eye tracking is used to test and validate the placement of visual stimuli in clinics, thereby supporting evidence-based operatory design [31].

5. Eye Tracking for the Pediatric Dentist

a. Monitoring Gaze Behavior during Procedures

Pediatric dentists often divide visual focus between the treatment site and the child's face. Effective gaze shifting has been linked to improved outcomes in behavior guidance during pediatric dental care [32]. Eye tracking can evaluate this visual multitasking and offer feedback to improve attention balance.

b. Training Visual Communication Skills

Dentists who employ visual contact more frequently with patients tend to foster greater trust and compliance [33]. Eye tracking identifies when a clinician is overly focused on instrumentation, ignoring facial cues of discomfort. This insight can improve communication-based training.

c. Behavioral Coaching and Self-Awareness

When used in training, eye tracking provides objective data to trainees about their visual strengths and gaps [34]. For example, missing a child's anxious glance while focusing on a matrix band can be highlighted as a missed behavioral cue—allowing correction before it impacts care.

Advantages and Limitations

Advantages

- Non-invasive, real-time behavioral data.
- Enhances patient-specific care and clinician training.
- Promotes ergonomic and workflow improvements.
- Empirical tool for validating distraction methods and operatory setups.

Limitations

- High equipment and maintenance costs. [35]
- Motion artifacts common in young children.
- Requires calibration and trained interpretation.
- Ethical concerns: data privacy and surveillance, particularly in pediatric settings [36]

Future Directions

Artificial Intelligence (AI) Integration

Machine learning models trained on large gaze datasets can detect anxiety patterns and recommend adaptive strategies [37]. AI can also automatically score performance or offer real-time alerts during patient interaction [38].

Tele-Dentistry and Remote Gaze Assessment

Screen-based eye tracking integrated with virtual consultations can pre-assess anxiety or behavior from home—streamlining clinic visits [39]. It can also be used in virtual oral health education to adapt interfaces based on child gaze response.

Longitudinal Behavioral Research

Tracking gaze over multiple appointments provides data on the evolution of fear, trust, and coping mechanisms. Such longitudinal studies will be pivotal in refining age-specific dental behavior management protocols [40].

Table 3: Presents seven peer-reviewed studies published between 2018 and 2024 that explored the application of eye-tracking methods in either pediatric patients or pediatric dental education [16, 41, 46]

	Year	Authors	Study Focus	Participants	Key Findings
1	2018	Celine G. *et al*.	Children's attention to dentist appearance	Children (4-12 years)	Focus on mouth; distracted by accessories
2	2020	Richter J. *et al*.	Training dental students on radiographs	Dental students	Improved anomaly detection post-training
3	2022	Cho V. Y. *et al*	Preschoolers' attention to dental caries	Preschoolers (2.5-5.5years)	No fixation bias toward caries
4	2022	Cho V. Y *et al*.	Visual response to midline diastema	Preschoolers & educators	Gaze split between exploratory and focused
5	2023	BhadilaG.Y. *et al*.	Residents analyzing panoramic radiographs	Pediatric dental residents	72% detection accuracy; influenced by location
6	2023	Bhadila. *et al*	Systematic review on cleft perception	Mixed-age observers	Significant difference in gaze patterns
7	2024	Winter L. *et al*	Comparison of low-cost eye-tracking tools	Dentists & dental students	Webgazer.js more accurate than Peye Tracker

Key Trends & Insights

Preschool-aged children were a primary demographic in research examining visual attention to dental conditions like cavities and gaps between teeth. These studies often employed Hidden Markov Models to differentiate how children process visual information. Dental students and professionals were evaluated on their ability to interpret panoramic dental X-rays. Their eye movement patterns—such as how long they fixated on certain areas and how often they returned to those spots—served as indicators of their diagnostic proficiency. In 2024, there was an increasing emphasis on assessing the effectiveness of affordable eye-tracking technologies, such as Webgazer.js and Peye Tracker, which may offer more accessible options for clinical and educational settings. A systematic review on cleft lip and palate perception demonstrated the value of eye-tracking in gauging not only clinical outcomes but also aesthetic judgments and visual biases held by viewers.

Conclusion

Eye tracking technology provides unparalleled access to the visual and behavioral experiences of both pediatric patients and their dentists. By translating subtle gaze cues into actionable data, it supports more precise, empathetic, and efficient dental care. Although barriers to widespread adoption remain, advances in affordability, AI integration, and remote accessibility are likely to cement its role in the future of pediatric dentistry. This technology is no longer a novelty—it is a lens into how we see, react, and care within the pediatric dental operatory.

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