Identifying Distracting Architectural Factors of the Therapeutic Environment and the Effect of Their Modification on Rehabilitation Outcomes in ADHD Children, The Implication of Eye Tracking System.

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Abstract

Introduction: Children with Attention-Deficit/Hyperactivity Disorder (ADHD) often experience heightened distractibility and sensory regulation difficulties that compromise their therapeutic engagement. Despite growing recognition of environmental influences on child behavior, limited research has objectively quantified how architectural factors impact rehabilitation outcomes. This study investigated the relationship between built environmental features and attentional performance among ADHD children and evaluated the effect of targeted spatial modifications on therapeutic engagement. **Methods:** A mixed-methods, within-subject design was implemented in two phases involving 36 children aged 8–12 years with clinically confirmed ADHD. Eye-tracking systems were used to measure fixation duration, saccadic frequency, and gaze dispersion during therapy sessions in baseline and modified environments. Environmental modifications included decluttering, neutral color adjustments, optimized lighting, and visual zoning. Standardized instruments, Short Sensory Profile 2 (SSP2), Conners Continuous Performance Test (CPT-3), and Strengths and Difficulties Questionnaire (SDQ), were administered pre- and post-intervention. **Results:** Results demonstrated significant reductions in fixation on irrelevant stimuli ($p < 0.01$), increased task-oriented gaze fixation ($p < 0.05$), and improved sensory regulation scores on the SSP2. Children showed fewer sensory over-responsivity behaviors (SSP2), improvement in sustained attention (CPT-3) and emotional regulation (SDQ). Engagement scores also increased significantly ($p < 0.001$). **Conclusion:** These findings confirm that physical space is a modifiable determinant of therapeutic success. Integrating environmental design with clinical practice supports an evidence-based framework for sensory-conscious rehabilitation. This interdisciplinary approach has implications for the design of therapy centers, classrooms, and inclusive educational environments optimized for neurodiverse children.

Keywords: ADHD, architecture, rehabilitation, eye tracking System, environmental psychology

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Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common neurodevelopmental conditions affecting children, characterized by patterns of inattention, hyperactivity, and impulsivity that interfere with learning, behavior, and emotional regulation. Global prevalence rates range from 5–7% in school-aged populations [1], and co-occurrence with sensory processing difficulties is increasingly documented [2]. These children often struggle to sustain attention, particularly in environments overloaded with sensory stimuli, leading to suboptimal therapeutic and educational outcomes [3].

The concept of sensory modulation suggests that an individual's ability to regulate response to sensory input underpins effective engagement in daily activities [3]. Children with ADHD frequently display atypical modulation, being either hyper or hypo-responsive to sensory cues, making them particularly

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vulnerable to environmental distraction. These deficits not only affect classroom learning but also extend to rehabilitation and therapy settings, where attentional focus is essential for skill acquisition and behavioral change [4].

Health architecture, the deliberate design of healthcare environments to promote healing and well-being, plays a critical role in the treatment and management of psychological disorders. Research in environmental psychology has demonstrated that well-designed spaces can reduce stress, anxiety, and aggression while fostering calmness, safety, and a sense of control [5]. Thus, health architecture is not merely aesthetic; it is a fundamental component of holistic mental healthcare, integrating spatial design with psychological and social dimensions of healing.

The built environment exerts measurable effects on cognitive and emotional states. Architectural variables such as lighting, spatial layout, color palette, acoustic design, and visual clutter influence sensory load and psychological comfort [6, 7]. For instance, bright fluorescent lighting or high-contrast color schemes can elevate arousal and stress, while neutral tones and organized spaces support calm and sustained attention. In therapeutic contexts, these environmental affordances can either enhance or inhibit intervention efficacy [8].

Despite this, research in rehabilitation often prioritizes intervention techniques, such as occupational therapy or behavioral training, while overlooking the influence of the surrounding physical environment [8,9]. A mismatch between a child's sensory profile and their therapy setting may unintentionally reduce treatment effectiveness. Addressing this gap requires integrating environmental psychology with neurodevelopmental rehabilitation.

Recent advances in eye-tracking technology offer new methods to empirically assess attention and visual engagement [10,11]. Eye tracking records where individuals look, how long they fixate, and how frequently they shift attention (saccades). These metrics provide objective indicators of distraction and task engagement, particularly useful in populations where self-report is unreliable, such as young or neurodiverse children [12,13]. Studies using eye-tracking with ADHD populations demonstrate distinct gaze patterns, more frequent fixations on irrelevant stimuli and reduced sustained attention toward tasks, reflecting underlying attentional control deficits [10,14].

In architecture and environmental design, eye-tracking has emerged as a promising diagnostic tool for evaluating user response to spatial features [11,15]. For example, Rosas et al. [11] showed that gaze patterns reveal subconscious visual attraction to specific architectural elements, suggesting practical design implications for minimizing distraction. Applying such methods in pediatric therapy settings enables precise identification of visual distractors, such as cluttered walls, bright windows, or misplaced mirrors that may compromise attention.

This study proposes a novel integration of clinical rehabilitation, architectural design, and behavioral technology to enhance outcomes for children with ADHD. By systematically identifying and modifying distracting environmental features, it aims to establish an evidence-based model for sensory-informed therapeutic environments.

The specific objectives are:

1. To assess the feasibility of using eye-tracking technology to identify visual distractors in therapeutic settings for ADHD children.
2. To implement environmental modifications reducing these distractors.
3. To evaluate the impact of these modifications on attention, engagement, and sensory regulation using behavioral and psychometric measures.
4. To develop a design framework linking environmental architecture with neurodevelopmental therapy.

This research aligns with the emerging paradigm of neuro-architecture, which posits that built spaces interact with neural processes to influence emotion, cognition, and behavior [16,17]. In the case of ADHD, a structured, low-stimulus environment may facilitate better attention regulation and adaptive functioning. The integration of environmental design with clinical data promises to shift rehabilitation toward more holistic, child-centered approaches where

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architecture is a therapeutic tool, not a passive backdrop.

Methods

Sampling

Thirty-six children aged 8–12 years (mean age = 9.7 ± 1.3) diagnosed with ADHD according to DSM-5 criteria were recruited from 6 pediatric rehabilitation centers in Tehran. Inclusion criteria included normal or corrected vision, ability to participate in structured tasks for 25 minutes, and parental consent. Exclusion criteria included uncorrected visual impairments, seizure disorders, or inability to tolerate assessments. Participants represented diverse socioeconomic backgrounds to improve generalizability.

Data Collection

Sessions were conducted in a standard therapy room measuring about 5m × 6m, equipped with adjustable lighting, shelves, desks, and visual displays. A desktop eye-tracking system (Segal iTracker, Farmed Tajhiz Co, Tehran, Iran, sampling rate: 60 Hz; accuracy ±0.5°) was used for both screen-based and spatial gaze tracking. Calibration was performed before each session using a five-point visual marker routine. A short static Film of the room was captured with the object task at the center of the screen. The children sat at the front of the screen and the film was displayed 30 seconds while they were looking at the screen. The children were instructed to look at the object task.
Short Sensory Profile 2 (SSP2) (that measures sensory processing across modalities), Conners Continuous Performance Test (CPT-3) (that evaluates sustained attention and impulsivity), strengths and difficulties questionnaire (SDQ) (that assesses behavioral and emotional regulation) were used to assess the improvement trends in the children in two phases of the study.

Study Design

A two-phase mixed-methods design was adopted. The study used a within-subject repeated-measures. Each child attended three assessment phases:

Phase 1: Baseline Observation

Children participated in 25-minute therapy sessions involving puzzle-solving and fine-motor tasks in the standard environment for 8 weeks. Eye-tracking data (fixation duration, saccades per minute, and heat maps) were recorded and SSP2, CPT-3, and SDQ were also administered pre and post the first phase.

Phase 2: Environmental Modification

Based on Phase 1 eye-tracking heat maps, distractor zones were minimized (e.g., removing bright objects near windows). Children received identical therapy sessions in the modified environment for another four weeks. After another eight weeks of therapy in the modified setting, all assessments were repeated to measure sustained change.
Environmental features that were modified between phases were:

- Lighting: Replaced fluorescent tubes with 4000K diffuse LED panels.

- Color scheme: Walls repainted in low-saturation hues (light grey-blue).

- Visual clutter: Removed excess posters and toys; shelves covered with neutral panels.

- Spatial zoning: Introduced visual partitions separating activity and play areas.

Qualitative Assessment

In addition to quantitative measurements, qualitative data were collected to capture the experiential and behavioral aspects of how children interacted with the therapeutic environment before and after modification. This approach allowed for a deeper understanding of changes in engagement, comfort, and attention that might not be fully represented by numerical scores.
A structured Therapist Engagement Checklist (TEC) was developed for this study, informed by established behavioral observation frameworks used in pediatric rehabilitation and early intervention [18,19]. The checklist included seven domains assessing task engagement, response to instruction, distraction, emotional regulation, social interaction, persistence, and overall engagement.

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A trained therapist served as an independent observer during each session. They used a structured Therapist Engagement Checklist (TEC) to document the child's behavioral responses, attention patterns, and emotional regulation throughout the 25-minute therapy period (Table 1). Observer provide narrative comments on notable events, such as distraction triggers or self-regulatory behaviors (e.g., fidgeting, gaze aversion, or withdrawal). Total Score Ranged from 7 to 35 and the higher scores indicate greater engagement and lower distraction.

Themes were merged with the quantitative findings (eye-tracking and behavioral test results) to provide a richer, convergent interpretation of the data. The qualitative data were used not only to contextualize quantitative results but also to refine environmental modifications. For example:

If multiple children showed distraction toward wall posters (observed and reported), those were removed in Phase 2. If therapists reported reduced anxiety after lighting changes, this was cross-validated with improved attention metrics.

This convergent mixed-methods design ensured that environmental design decisions were both data-driven and experientially informed.

This checklist provides a standardized yet flexible structure for behavioral observation, ensuring that subtle changes in engagement and affect are systematically captured across sessions.

Data Analysis:

Eye-tracking data, SSP2, CPT-3, SDQ and TEC scores were analyzed. Paired T-Tests compared the improvements of the dependent variables in two phases of the study. Effect sizes (Cohen's d) were computed. A p-value < 0.05 was considered statistically significant.

Table 1 Therapist Engagement Checklist (TEC)

Domain	Observed Behavior	Scoring (1–5)	Notes/Examples
Task Engagement	Sustains attention to task for ≥2 minutes	1 = Never → 5 = Always	Frequency and duration of active participation
Response to Instruction	Follows therapist's cues without delay	1 = Rarely → 5 = Consistently	Measures cooperation and comprehension
Distraction Level	Looks away or attends to irrelevant stimuli	1 = Frequent → 5 = Rarely	Eye or body orientation toward distractors
Emotional Regulation	Appears calm and emotionally stable	1 = Distressed → 5 = Relaxed	Signs: fidgeting, vocal outbursts, avoidance
Social Interaction	Engages positively with therapist/peers	1 = Withdrawn → 5 = Actively social	Eye contact, responsiveness, verbal exchange
Persistence	Returns to task after interruption	1 = Not at all → 5 = Always	Measures self-regulation and resilience
Overall Engagement Rating	Global therapist impression	1 = Very poor → 5 = Excellent	Summary judgment for session

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Results

Eye tracking results

Eye-tracking data revealed significant reductions in visual distraction and improved focus following environmental redesign (Table 2 & Figure 1). The proportion of fixations directed toward task stimuli increased by 33%, while distractor fixations declined by nearly half (p < 0.001).

Behavioral and Sensory Assessments (table 3)

All behavioral measures indicated improvement post-modification. Children exhibited fewer sensory over-responsivity behaviors (SSP2), enhanced sustained attention (CPT-3), and better emotional regulation (SDQ). Engagement scores increased significantly (p < 0.001) (figure 2).

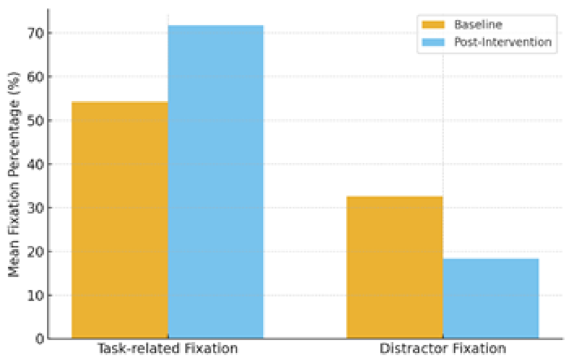

Figure 1 Mean fixation percentage on task-related and distractor stimuli before and after environmental modification. Bars represent mean values ± SD.

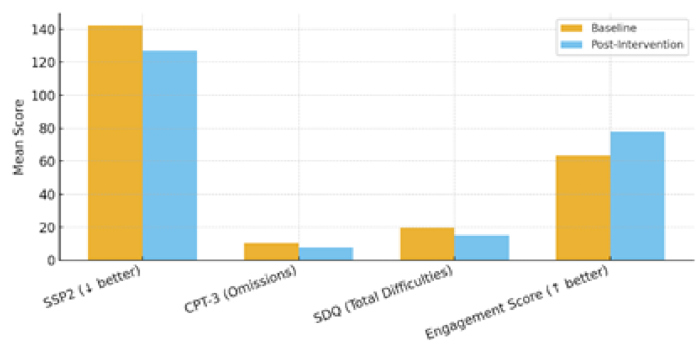

Figure 2: Behavioral and Regulation Scores Before and After Environmental Modification

Table 2. Eye-tracking Metrics Before and After Environmental Modification (n = 36)

Variable	Baseline (mean ± SD)	Post-intervention (mean ± SD)	P-value	Effect size
Fixation on task-related stimuli (%)	54.2 ± 11.5	71.8 ± 10.3	<0.001	0.89
Fixation on distractors (%)	32.6 ± 9.8	18.4 ± 7.9	<0.001	0.94
Mean fixation duration (ms)	210 ± 65	278 ± 72	0.008	0.62
Saccades per minute	118 ± 23	97 ± 21	0.002	0.55

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Table 3. Standardized Test Scores Pre- and Post-Intervention

Measure	Baseline mean (SD)	Post-intervention mean (SD)	Δ score	P-value
SSP2 total (lower = better)	142.3 (19.4)	127.1 (17.2)	- 15.2	0.009
CPT-3 omissions	10.6 (3.4)	7.9 (3.1)	- 2.7	0.021
SDQ total difficulties	19.8 (5.1)	15.2 (4.7)	- 4.6	0.016
Therapist engagement checklist	63.4 (9.6)	77.8 (8.2)	+14.4	<0.001

Qualitative Findings

Three recurring themes emerged:

1. Calmer Engagement: Therapists reported reduced restlessness and more consistent participation.

2. Visual Clarity: Children appeared less visually overwhelmed, often maintaining longer eye contact with the therapist.

3. Spatial Predictability: Parents noted children's preference for the "organized" layout, linking it to improved transitions between activities.

Together, these findings support the hypothesis that environmental simplification enhances therapeutic engagement.

Discussion

This study demonstrates that modifying architectural elements within therapy environments can produce measurable improvements in attention and behavior among children with ADHD. Eye-tracking data confirmed that baseline therapy rooms contain numerous visual distractors that divert gaze from task-relevant stimuli. Following strategic environmental redesign, attentional focus improved significantly, accompanied by behavioral regulation gains.

The reduction in gaze dispersion and increased fixation on relevant stimuli align with prior research indicating that ADHD children exhibit heightened visual distractibility [10,14]. Environmental simplification effectively minimized external competition for attention, validating the theoretical framework of sensory modulation [3]. This supports findings by Bodison and Parham [8] showing that sensory environmental modifications enhance participation in children with sensory integration difficulties.

Improved SSP2 and SDQ scores further suggest that environmental design can influence not only attention but emotional and sensory comfort. Consistent with Nair et al. [6] and Sathyanarayanan et al. [7], lighting and color adjustments reduced overstimulation, contributing to calmer engagement. The strong correlation between reduced distractor fixations and improved CPT-3 attention metrics ($r = 0.62$, $p < 0.01$) indicates that attentional improvement was not coincidental but functionally linked to spatial redesign.

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Few studies have integrated eye-tracking with spatial intervention in pediatric therapy. Stokes et al. [10] and Chan et al. [13] demonstrated that eye-tracking can quantify attention patterns in ADHD and ASD children; however, their work remained diagnostic. The present study extends this application into therapeutic optimization, showing that eye-tracking can guide architectural interventions.

Environmental psychology posits that visual complexity affects cognitive load. Rosas et al. [11] confirmed that specific environmental features, contrast ratios, object density, modulate gaze behavior. By translating these principles to therapy rooms, the present study provides empirical evidence supporting neuro-architectural adaptation for developmental disorders.

Results support ecological models of development, which emphasize the dynamic interaction between individuals and their contexts. ADHD-related attention deficits are not purely neurological but are shaped by environmental affordances [16, 17]. Hence, architecture should be regarded as part of the therapeutic "treatment team," influencing behavior alongside therapists and interventions.

For clinicians, simple design interventions, such as reducing clutter, using neutral tones, and controlling natural light, can enhance treatment efficiency. Educators can apply these findings to classroom design, promoting learning for neurodiverse students. Architects gain actionable metrics on how spatial characteristics affect cognition and behavior, enabling evidence-based design.

This pilot study used a small sample and simulated environmental adjustments within controlled settings; replication in real-world schools and therapy centers is essential. Eye-tracking captures visual attention but not auditory or tactile distractions, which may also influence outcomes. Future studies could integrate multimodal sensors (EEG, heart rate variability) to correlate physiological arousal with environmental features. Longitudinal designs may reveal whether sustained exposure to optimized environments yields durable behavioral improvements.

The integration of architecture and neuroscience epitomized here has implications beyond ADHD. Similar principles could guide the design of environments for autism, learning disabilities, and emotional regulation disorders [17,20,21]. The study contributes to a growing discourse on "healing architecture" —the design of spaces that actively support therapeutic processes.

This study highlights that therapeutic environment exert measurable influence on attentional performance and behavioral outcomes in children with ADHD. Using objective eye-tracking metrics, it identified specific architectural features, visual clutter, lighting, and spatial layout that distract from therapy. Systematic modification of these factors significantly improved attention, sensory regulation, and engagement.

Findings underscore the necessity of treating environmental design as an integral therapeutic variable. Modest, low-cost spatial interventions can substantially enhance rehabilitation effectiveness. The convergence of quantitative and qualitative data validates the feasibility of eye-tracking–guided design as an innovative tool for clinical practice and education.

However, results should be interpreted within limitations: modest sample size, short-term follow-up, and focus on visual rather than multisensory stimuli. Future research should employ larger cohorts, longitudinal designs, and multimodal measurement to refine evidence-based design standards.

Ultimately, this work advocates for interdisciplinary collaboration between clinicians, architects, and educators in creating inclusive, sensory-conscious environments that enable all children, regardless of neurological profile, to thrive.

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Ethical consideration

All participants and their legal guardians were fully informed about the study's aims and procedures. Participation was entirely voluntary. Written informed consent was obtained from parents or legal guardians prior to data collection, and verbal or written assent was obtained from all children when appropriate to their developmental level. The study involved only non-invasive assessments and environmental modifications within standard therapeutic contexts. No experimental intervention was done on the children and data confidentiality and

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participant anonymity were strictly maintained throughout the research process. Ethical approval for this study was obtained from Islamic Azad University ethics committee (Code: 18160202952016).

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Conflict of interest
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Authors' contributions
All authors contributed equally to the preparation of this article.

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