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Immersive Quiet Rooms for Children with ADHD: Color, Geometry, and Gaze Based Simulation

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Keywords
ADHD children; immersive environment; quiet room design; color psychology; geometric design; gaze-based simulation.

ABSTRACT
Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental condition characterized by difficulties in maintaining attention, regulating sensory responses, and managing behavioral impulses. Environmental design has increasingly been recognized as a supportive intervention that can influence emotional regulation and cognitive performance among children with ADHD. This study explores the design of immersive quiet rooms through the integration of color, geometric elements, and gaze-based simulation to create a calming and adaptive environment for children with ADHD. The research employs a design simulation approach by examining how spatial configurations, visual stimuli, and interactive environmental features affect children's attention patterns and sensory experiences. A virtual immersive environment was developed to evaluate the impact of different color schemes, geometric compositions, and visual focal points using gaze-based interaction analysis. The findings indicate that carefully selected soft color palettes, balanced geometric patterns, and controlled visual stimuli contribute to improved sensory comfort and reduced visual distraction. The gaze-based simulation demonstrates that specific spatial arrangements and visual elements can guide attention toward calming areas while minimizing overstimulation. This study highlights the potential of immersive quiet rooms as an evidence-based environmental strategy to support children with ADHD by integrating architectural design principles with digital simulation technologies. The proposed approach provides new insights into designing therapeutic learning and relaxation spaces that are responsive to children's sensory needs and cognitive characteristics.

INTRODUCTION

Learning and sensory regulation spaces for children with ADHD should not be treated as neutral containers. Children with ADHD often experience difficulties in sustaining attention, inhibiting irrelevant stimuli, and regulating body movements when the environment contains excessive visual inputs. In architectural and interior design contexts, these inputs may be introduced through wall color, brightness, correlated color temperature, contrast, visual density, geometric patterns, spatial rhythm, and the overall level of visual clutter.

Consequently, an immersive quiet room must be designed as a controlled visual environment rather than merely an empty or isolated space (Cucinella et al., 2025; Stepanova et al., 2019).

Previous studies suggest that color and lighting can influence attention, memory, mood, and spatial comfort. Llinares et al. (2021) demonstrated that cool and warm classroom colors affect psychological and neurophysiological responses related to attention and memory. Within the ADHD context, Öktem and Olguntürk (2019) examined how framing and the color red influenced in-class performance among children with ADHD. Nair et al. (2022) further showed that light and color in the built environment were associated with behavioral responses among autistic children. Although autistic populations are not identical to ADHD populations, these findings remain valuable within neurodiversity research because both groups may exhibit heightened sensitivity to sensory stimuli.

METHOD

This study used a systematic literature review design with a mixed synthesis approach. The qualitative component was used to interpret design principles, sensory regulation concepts, and neuroarchitecture perspectives. The quantitative component was treated as evidence mapping because the included studies differed in population characteristics, instruments, exposures, and outcomes. Therefore, quantitative findings were not pooled into a single effect size; instead, they were mapped to demonstrate the availability and strength of empirical evidence.

The review followed four main stages: (1) identification of records from databases and other academic search sources; (2) removal of duplicates and title–abstract screening; (3) full-text eligibility assessment based on population, exposure, outcome, context, methodology, publication type, language, and indexation criteria; and (4) final synthesis through thematic coding and quality-relevance scoring.

The search strategy used the following combination of keywords: ("ADHD" OR "attention deficit hyperactivity disorder" OR neurodivergent OR neurodiversity) AND ("quiet room" OR "quiet space" OR "sensory room" OR "calming space" OR "immersive environment" OR "virtual environment") AND ("visual comfort" OR color OR colour OR lighting OR geometry OR geometric OR pattern OR "visual clutter") AND (attention OR focus OR concentration OR distraction OR gaze OR "eye tracking").

The databases and sources included Scopus, Google Scholar, and PubMed. These sources were selected to capture literature from architecture and interior design, neurodiversity, health-related research, and interdisciplinary fields that may not be represented within a single indexing system. The search process was further refined based on publication year, publication type, language, full-text availability, study relevance, and applicability to immersive quiet room design.

Table 1. Inclusion and exclusion criteria

Criteria	Operational definition
Population	Children with ADHD or transferable neurodivergent / sensory populations; non ADHD samples retained only when the visual / spatial variable was strongly transferable.
Exposure / variable	Color, lighting, visual comfort, geometric pattern, visual clutter, quiet room, sensory room, immersive environment, virtual reality, or eye-tracking/gaze-based screening.

Outcome	Attention, focus, distraction, gaze, comfort, emotion, behavior, body movement, working memory, or visual task performance.
Context	Learning spaces, quiet spaces, sensory inclusive spaces, interior environments, virtual environments, or architectural design contexts.
Exclusion	Thesis / dissertation, book, non empirical opinion, non peer reviewed source, irrelevant population, no visual spatial variable, no relevant outcome, weak method, unavailable full text, and insufficient spatial/visual relevance.

Table 2. Quality relevance scoring structure

Assessment block	Number of criteria	Maximum score	Function in review
Relevance subtotal	4 criteria	20 points	Topic relevance, location / context, research object, and variable / research focus.
Quality subtotal	6 criteria	30 points	Publication type, publication year, language, full-text availability, method appropriateness, and methodological quality.
Actualization and contribution subtotal	5 criteria	25 points	Citation/reputation, novelty, depth of analysis, theoretical contribution, and practical contribution.
Total score	15 criteria	75 points	Main evidence >=84%; strong supporting evidence >=72%; supporting evidence >=60%.

Data quality control: each final study was evaluated using 15 criteria with a 1-5 scoring scale. The total possible score was 75. The appraisal was not used to exclude all weaker studies automatically; instead, it determined whether a study functioned as main evidence, strong supporting evidence, or supporting evidence. This prevents conceptual or cross-diagnosis studies from being overclaimed as direct causal evidence for ADHD quiet room design.

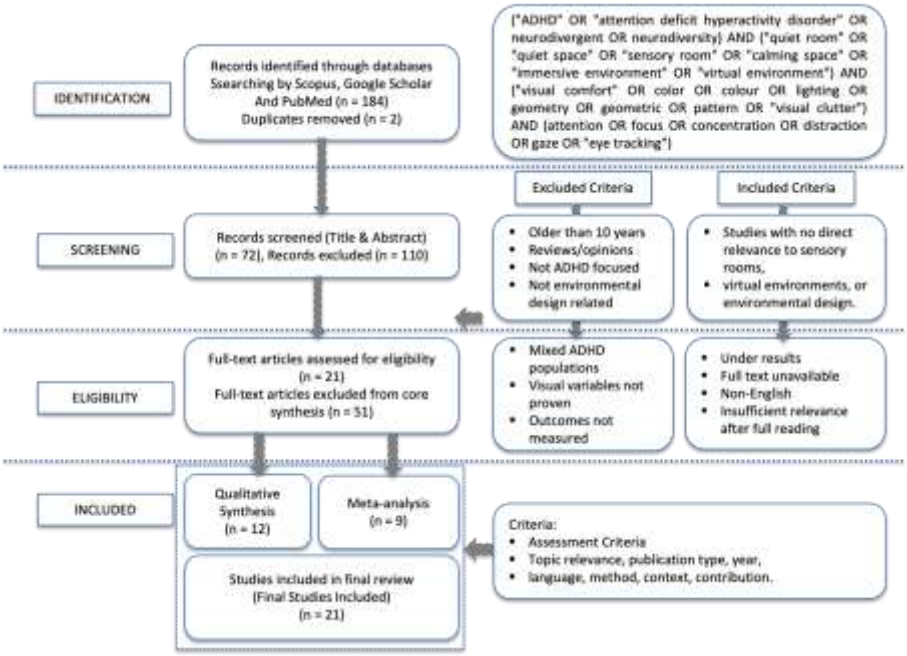

Figure 1. PRISMA flowchart for the systematic literature review process

Table 3. Numerical summary of the PRISMA flow

PRISMA phase	Decision point	n

Identification	Records identified from databases and other academic sources	184
Identification	Duplicates removed	2
Screening	Records excluded after screening	110
Screening	Records screened by title and abstract	72
Eligibility	Full-text articles excluded from core synthesis	51
Eligibility	Full-text articles assessed and retained	21
Included	Studies included in qualitative synthesis	12
Included	Studies included as meta-analysis/evidence mapping	9
Included	Final studies included in review	21

RESULT AND DISCUSSION

Study Characteristics and Evidence Composition

The final review contained 21 studies published between 2017 and 2025. Most studies were recent: 16 studies (76.2%) were published from 2020 onward, and 9 studies (42.9%) were published from 2023 onward. The synthesis pathway consisted of 12 qualitative synthesis studies (57.1%) and 9 meta-analysis / evidence mapping studies (42.9%).

Quantitative evidence reading: the quality relevance appraisal produced a mean score of 62.24/75 (82.98%), with scores ranging from 51 to 70 (68.0% to 93.3%). The mean relevance subtotal was 16.14/20, the mean methodological quality subtotal was 24.95/30, and the mean actualization-contribution subtotal was 21.14/25. These values indicate that the final dataset was suitable for synthesis but still required careful interpretation because not all studies directly involved children with ADHD or immersive quiet rooms.

Table 4. Quantitative composition of the final evidence set

Indicator	Frequency	Percentage
Total final studies	21	100%
Qualitative synthesis	12	57.1%
Meta - analysis/evidence mapping	9	42.9%
Primary evidence weight	9	42.9%
Supporting evidence weight	10	47.6%
Conceptual evidence weight	2	9.5%
Eligible: main evidence	9	42.9%
Eligible: strong supporting evidence	8	38.1%
Eligible: supporting evidence	4	19.0%

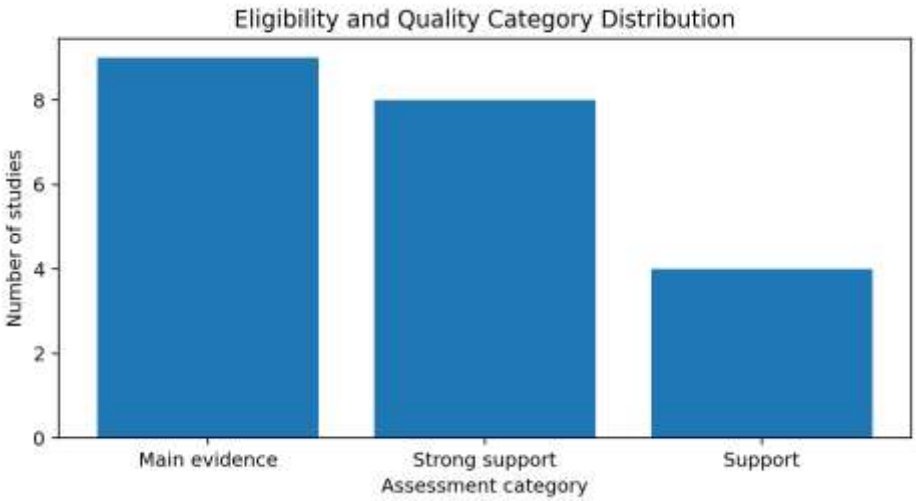

Figure 2. Distribution of eligibility and quality categories.

Table 5. Final included studies and their function in the synthesis

No.	Study title	Year	Synthesis path	Weight	Theme	Use in SLR
1	A Neurocognitive Study of the Emotional Impact of Geometrical Criteria of Arc...	2021	Meta-analysis/evidence mapping	Primary	T2	Main evidence for geometric patterns and VR - eye tracking
2	A Case Study on the Effect of Light and Colors in the Built Environment on Au...	2022	Qualitative synthesis	Supporting	T1	Cross-diagnosis support for color and lighting
3	ADHD, Expression, and the Incorporeal Materialism of Movement	2017	Qualitative synthesis	Conceptual	T5	Conceptual basis for movement regulation
4	Classroom versus Individual Working Memory Assessment: Predicting Academic Ac...	2020	Meta-analysis/evidence mapping	Supporting	T5	Support for distraction control and ecological validity
5	Cold and Warm Coloured Classrooms: Effects on Students' Attention and Memory ...	2021	Meta-analysis/evidence mapping	Primary	T1	Main evidence for color and virtual simulation

No.	Study title	Year	Synthesis path	Weight	Theme	Use in SLR
6	Designing Learning Environment for School Children Having Attention-Deficit/H...	2024	Qualitative synthesis	Supporting	T5	Support for ADHD spatial organization
7	Designing Sensory-Inclusive Virtual Play Spaces for Children	2019	Qualitative synthesis	Supporting	T3	Support for personalized immersive simulation
8	Designing for Special Neurological Conditions: Architecture Design Criteria f...	2025	Qualitative synthesis	Conceptual	T2	Conceptual basis for immersive anti-ADHD spaces
9	Development of Learning Facilities for ADHD Student Aged 6–9 Years Old at a S...	2023	Qualitative synthesis	Supporting	T5	Support for furniture, muted colors, and active seating
10	Dynamic Seat Assessment for Enabled Restlessness of Children with Learning Di...	2022	Meta-analysis/evidence mapping	Primary	T5	Main evidence for active seating and controlled movement
11	Effects of Framing and the Color Red on In-Class Performances of Children wit...	2019	Meta-analysis/evidence mapping	Primary	T1	Main evidence for color framing in ADHD
12	Efficacy of a Virtual Reality Biofeedback Game (DEEP) to Reduce Anxiety and D...	2020	Meta-analysis/evidence mapping	Supporting	T4	Support for VR-based regulation intervention
13	Enhancing Educational Spaces for Neurodiverse Learners: Design Standards and ...	2025	Qualitative synthesis	Supporting	T3	Support for neurodivergent quiet-zone standards
14	Creating the Conditions for Inclusion: Investigating	2024	Qualitative synthesis	Supporting	T3	Support for quiet spaces for adult neurodivergent users

No.	Study title	Year	Synthesis path	Weight	Theme	Use in SLR
	Optimal Physical Spaces ...					
15	Home Indoor Environmental Quality and Attention Deficit Hyperactivity Disorder	2023	Meta-analysis/evidence mapping	Primary	T6	Main evidence for IEQ and ADHD
16	How Interior Design Responds to Neurodiversity: Implementing Wearable Technol...	2023	Qualitative synthesis	Primary	T4	Methodological basis for RealEye, IVR, and triangulation
17	Leveling the Playing Field: Supporting Neurodiversity via Virtual Realities	2018	Qualitative synthesis	Supporting	T4	Cross-diagnosis support for VR
18	Putting the Sensory Individual at the Centre of Architectural Design	2024	Qualitative synthesis	Primary	T2	Main evidence for pattern glare and visual clutter
19	Spatial Design Makes a Difference in Student Academic Engagement Levels: A Pi...	2017	Meta-analysis/evidence mapping	Supporting	T5	Support for engagement and movement
20	The Effects of Interior Design on Wellness: Eye Tracking Analysis in Determin...	2020	Meta-analysis/evidence mapping	Primary	T4	Main methodological evidence for interior eye tracking
21	Understanding and Supporting Attention Deficit Hyperactivity Disorder (ADHD) ...	2023	Qualitative synthesis	Primary	T3	Main evidence for personalization and ADHD behavioral observation

Thematic Synthesis

The thematic synthesis produced one umbrella theme: the effectiveness of immersive quiet rooms for children with ADHD depends on adaptive regulation of visual stimuli. This regulation includes controlled color and lighting, readable geometric patterns, distraction

management, movement accommodation, and multimodal validation through simulation or RealEye Web, behavioral observation, and visual-task performance.

Table 6. Thematic analysis of the 21 final studies

Code	Analytical theme	Studies (n)	Final study no.	Design/research implication
T1	Visual stimulus calibration: color, lighting, contrast, and visual clutter	3	2, 5, 11	Provides the basis for calibrating color, lighting, contrast, and visual clutter so that visual stimuli do not trigger excessive distraction.
T2	Geometry, pattern regularity, and spatial readability as response moderators	3	1, 8, 18	Supports the selection of predictable, regular, and readable geometrical patterns that avoid excessive visual load.
T3	Quiet space as a personal, flexible, multisensory self-regulation setting	4	7, 13, 14, 21	Frames the quiet room as a flexible sensory regulation space that must respond to individual sensory needs.
T4	Immersive simulation and gaze-based screening before spatial implementation	4	12, 16, 17, 20	Supports the use of simulation and RealEye Web as indicative screening before testing a real immersive quiet room.
T5	ADHD focus supported by controlled distraction and directed movement regulation	6	3, 4, 6, 9, 10, 19	Justifies the integration of focus, distraction, body movement, and task performance in behavioral observation.
T6	Visual comfort as part of indoor environmental quality and restorative setting	1	15	Positions visual comfort within a broader IEQ and restorative environment system rather than as an isolated aesthetic variable.

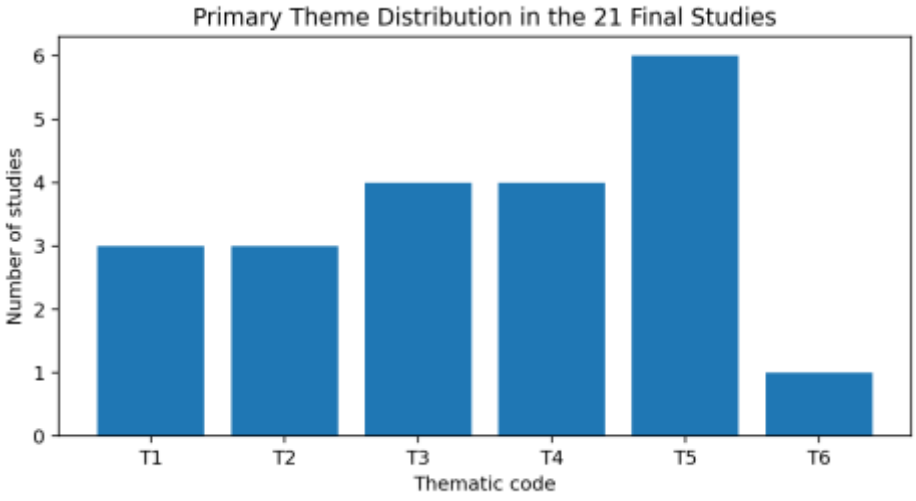

Figure 3. Distribution of primary themes across the final studies.

Theme 1: Visual Stimulus Calibration

The first theme shows that color, lighting, contrast, and visual clutter must be calibrated as interacting variables. Llinares et al. (2021) and Öktem and Olguntürk (2019) provide the most direct evidence on color and attention/performance, while Nair et al. (2022) adds transferable neurodiversity evidence on visual sensitivity to light and color. The synthesis does not imply that a single color is universally optimal. Instead, it supports a calibrated palette strategy with controlled saturation, low glare, readable contrast, and minimal unnecessary visual objects.

Design implication: color selection in an immersive quiet room should be tested as a controlled visual exposure variable. Candidate colors should be presented through simulation, screened using RealEye Web indicators such as time to first fixation, fixation count, and dwell time, and then validated through behavioral observation and task performance.

Theme 2: Geometric Pattern Readability

The second theme indicates that geometrical stimuli may shape emotional and cognitive responses. Shemesh et al. (2021) offers primary evidence that scale, symmetry, proportion, protrusion, and curvature affect neurocognitive responses in virtual environments. Leonards et al. (2024) and Abdallah (2025) strengthen the argument that sensory responsive architecture should avoid excessive visual complexity, unpredictable patterning, and visual stressors.

Design implication: geometric patterns for immersive quiet rooms should be predictable, readable, rhythmically stable, and visually low to moderate in complexity. Pattern selection should avoid visual clutter, pattern glare, and strong directional conflicts that may increase cognitive load or trigger unnecessary scanning.

Theme 3: Quiet Space as Personalized Sensory Regulation

The third theme reframes quiet space as an adaptive sensory-regulation setting rather than a fixed room typology. Boyd (2019), Riordan et al. (2024), Rao et al. (2025), and McDougal et al. (2023) show that neurodiverse users and children with ADHD may require spaces that support control, predictability, retreat, social modulation, and flexible sensory input. Therefore, immersive quiet rooms should not be designed as one size fits all environments.

Design implication: the quiet room must provide adjustable visual scenarios and a clear transition between stimulation and rest. The design should allow the child to remain engaged without being forced into complete stillness, because movement can also function as a self-regulation strategy.

Theme 4: Immersive Simulation and Gaze Based Screening

The fourth theme supports the use of immersive simulation and gaze-based screening before physical implementation. Bossenbroek et al. (2020), Kwon et al. (2023), Boyd et al. (2018), and Tuszyńska-Bogucka et al. (2020) demonstrate the methodological value of virtual environments, wearable technologies, and eye tracking in assessing spatial experience. In this review, RealEye Web is positioned not as a definitive diagnostic tool but as an indicative screening instrument for identifying visual stimuli that may attract, hold, or distract attention.

Design implication: RealEye Web should be integrated into a triangulated protocol. Gaze data should be interpreted alongside CCTV based behavioral observation, verbal response when available, task completion time, task accuracy, and signs of comfort or restlessness.

Theme 5: Distraction and Directed Movement Regulation

The fifth theme is the largest cluster, with six final studies. It emphasizes that focus in ADHD is not merely the absence of movement but the capacity to sustain task engagement despite internal and external distractions. Levin (2017) provides a conceptual basis for interpreting ADHD movement affirmatively, while Friso van den Bos and van de Weijer-Bergsma (2020), Kamal et al. (2024), Stanić et al. (2022), Tristiyono and Tualeka (2023), and Scott-Webber et al. (2017) highlight the relevance of spatial organization, furniture, and ecological validity for attention and engagement.

Design implication: immersive quiet rooms should reduce irrelevant stimuli while still permitting directed and safe micro movements. Observational indicators should include looking away, fidgeting, standing, chair movement, interaction with light/projector, task persistence, and emotional expression.

Theme 6: Indoor Environmental Quality and Restorative Context

The sixth theme, represented by Alizadeh et al. (2023), places visual comfort within the broader system of indoor environmental quality. This theme is not the strongest direct evidence for color or geometry, but it reminds designers that visual comfort interacts with air, acoustics, thermal comfort, lighting, and restorative environmental features. An immersive quiet room should therefore be understood as a controlled IEQ setting rather than a purely visual installation.

Translation into Preliminary Design Criteria

Table 7. Evidence-based translation into immersive quiet-room design criteria

Design aspect	Preliminary criterion	Operational indicator	Literature basis
Color and lighting	Use soft or calibrated color palettes, avoid excessive brightness and strong saturation, control glare and contrast.	TTFF, fixation count, dwell time, pupil change, observed comfort, task accuracy.	Llinares et al.; Öktem & Olguntürk; Nair et al.
Geometric pattern	Prioritize regular rhythm, stable repetition, low-to-moderate complexity, and readable spatial composition.	AOI heatmap, scanpath, error rate, hesitation, restlessness, and task-completion time.	Shemesh et al.; Leonards et al.; Abdallah
Quiet-space setting	Design as adjustable sensory regulation, not as a static isolation room; allow controlled retreat and recovery.	Child preference, duration of task engagement, teacher / observer notes, comfort expression.	Boyd; Riordan et al.; McDougal et al.
Simulation and RealEye	Use RealEye Web as pre-implementation screening to select candidate color-pattern scenarios.	TTFF, fixation count, dwell time, AOI attention, triangulated CCTV, and task performance.	Kwon et al.; Tuszyńska-Bogucka et al.; Bossenbroek et al.
Movement regulation	Provide safe and directed micro-movement opportunities; do not classify all movement as loss of focus.	Turning away, fidgeting, standing, chair shifting, task persistence, emotional expression.	Levin; Stanić et al.; Friso-van den Bos & van de Weijer-Bergsma

Theoretical and Practical Implications

Theoretically, this review integrates neuroarchitecture, neurodiversity oriented interior design, and gaze based evaluation into a single working model. Visual comfort is interpreted as a mechanism that can reduce cognitive load, which then supports attention stability, lowers distraction, and improves task performance. This model is consistent with the reviewed evidence but must still be tested empirically in children with ADHD through controlled simulation and real-room observation.

Practically, the review offers a design protocol: identify candidate colors and geometric patterns, screen visual attention through RealEye Web, select lower risk visual scenarios, and validate them through observation and visual task performance. This protocol moves the design process away from purely aesthetic preference and toward evidence informed environmental calibration.

Limitations and Future Research

Several limitations must be acknowledged. First, the final studies were heterogeneous in population, including children with ADHD, autistic children, neurodivergent users, students, and adult non clinical participants. Second, meta analysis group could not be statistically pooled because outcomes and instruments varied. Third, the quality relevance rubric was an internal appraisal system and did not replace formal risk of bias tools such as RoB 2 or ROBINS-I. Fourth, some conceptual and cross diagnosis studies were retained only as supporting evidence, not as direct proof of effectiveness for children with ADHD.

Future research should test selected color and geometric pattern scenarios in controlled immersive simulations and real quiet room settings with children with ADHD. The next protocol should combine RealEye Web, CCTV based behavioral coding, visual tasks such as spot the difference or maze mapping, comfort indicators, and task performance metrics. This would allow the evidence map from the present review to become an empirically verifiable design protocol.

CONCLUSION

This systematic literature review concluded that immersive quiet rooms for children with ADHD should be developed through adaptive regulation of visual stimuli. The 21 final included studies indicated that color, lighting, contrast, geometric pattern regularity, visual clutter, quiet space flexibility, and movement accommodation were the main variables that needed to be controlled before implementation.

The review answered the research question by demonstrating that color and geometric patterns did not influence focus as isolated design elements. Instead, they operated through interconnected mechanisms involving visual comfort, cognitive load, distraction control, emotional comfort, and task performance. RealEye Web could support this process as an indicative gaze-based screening tool; however, it should not be considered the sole determinant of attentional outcomes. Its results should be triangulated with behavioral observations and visual task performance assessments.

The major contribution of this article was the evidence-informed translation of fragmented research from neurodiversity, color, geometry, quiet space design, virtual reality, and eye-tracking studies into preliminary design criteria for immersive quiet rooms. Further

research should validate the proposed criteria through controlled simulations and real-world room experiments involving children with ADHD.

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