I Can Do It Better: A Creative VR Latte Art–Based Approach to Cognitive and Motor Skills Training for Adults with ADHD

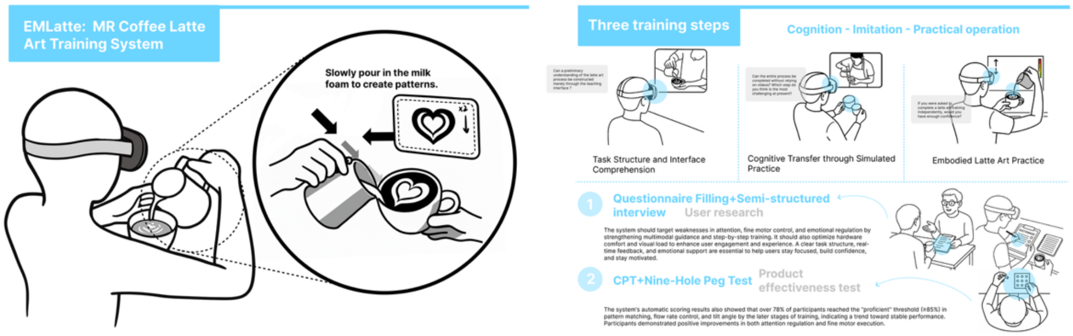

Figure 1: EMLatte: A Mixed Reality System for Cognitive and Fine Motor Training through Latte Art

Adult populations with attention deficit hyperactivity disorder (ADHD) frequently encounter challenges in sustaining attention and coordinating fine motor skills, thereby impairing their ability to perform daily tasks demanding concentration and accuracy. The present study designed an embodied interaction platform, EMLatte, introducing a mixed reality (MR) latte art training–based intervention in which participants, equipped with a Vision Pro, operate actual latte art instruments to complete tasks in a seamlessly integrated virtual–real environment, thereby fostering motor memory and physical involvement. The intervention segmented the training procedure into three progressive phases, embedding Reflection Prompts (RP) at critical points to cultivate participants' metacognitive awareness and deepen their understanding of the tasks. Upon completion of the two-week program, participants exhibited improvements in attention modulation as well as fine motor performance. This research seeks to offer an enjoyable and innovative tool for non-drug interventions targeting adult ADHD, and to illustrate how MR embodied interaction approaches can serve as a bridge linking skill learning with cognitive therapy.

CCS CONCEPTS • Human-centered computing → Mixed / augmented reality • Human-centered computing → User studies • Applied computing → Health informatics • Applied computing → Computer-assisted instruction

Keywords: Embodied interaction, ADHD, Fine Motor Skills, Attention Regulation, Reflective Prompts

1 INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) represents a common neurodevelopmental condition that, in adults, manifests as enduring impairments in cognitive control, executive functioning, and emotion regulation, affecting an estimated 2.5%–3.4% of the global adult population over their lifetime. Beyond reduced sustained attention, adult ADHD patients frequently encounter difficulties in the precise control of fine motor movements. While medication can be efficacious, its long-term administration carries potential adverse health effects. While medication can be efficacious, its long-term administration carries potential adverse health effects. Cognitive-behavioral interventions may improve cognitive functioning; however, their direct effect on fine motor proficiency is constrained, and specialized therapeutic resources are often scarce. Recently developed digital therapeutics have opened new avenues for the treatment of ADHD.

Empirical evidence from multiple studies indicates that game-oriented cognitive training substantially enhances objective measures of attention in ADHD patients.

The research introduces EMLatte, an MR-based coffee latte art training platform designed to replicate realistic latte art learning contexts for enhancing attentional modulation and fine motor control abilities in adult ADHD individuals. The practice of latte art requires several skills, such as hand–eye coordination, motor steadiness and the ability to focus for a sustained period of time. It is a demanding yet enjoyable fine motor task. This study hypothesizes that engaging in a three-tiered sequence of MR latte art exercises, supplemented with reflection prompts to facilitate self-monitoring and self-reflection, will significantly improve attentional focus and fine manual dexterity in adult ADHD participants, thus providing an innovative non-drug rehabilitation strategy.

At the initial phase of the study, questionnaires and semi-structured interviews were administered to six adults diagnosed with ADHD to gather baseline measures concerning attention regulation, fine motor cognition, emotional status, and receptiveness to technology. Drawing on the research outcomes to inform both theoretical underpinnings and user-centered perspectives, the system was finalized and then subjected to evaluation by 23 ADHD participants. Findings revealed that participants exhibited notable enhancements in attention control and the execution of fine motor tasks. Across the system’s recorded key performance indicators, over 78% of participants achieved the predefined “proficiency” criterion (⩾85% performance rate) in the latter stages of training. The study offers an evidence-based foundation for ADHD intervention strategies that merge immersive training with multimodal perceptual feedback, thereby extending the paradigm of embodied interaction technology applications in neurocognitive disorder contexts.

2 RELATED WORK

2.1 Traditional ADHD Treatment Methods

In clinical practice, interventions for ADHD generally involve pharmacotherapy, behavioral interventions, or an integrated approach combining the two. Medication, predominantly central nervous system stimulants, has been shown to effectively improve core symptoms including deficits in attention and impulse control [1]. Nevertheless, medication side effects, particularly in adults where insomnia, heightened anxiety and increased blood pressure are common, pose significant concerns and often result in limited long-term compliance.

Behavioral interventions typically encompass cognitive behavioral therapy (CBT), time management skills training, and organizational strategies, aiming to strengthen executive functioning and the capacity to manage daily activities [2]. Although such methods yield measurable benefits for cognitive-behavioral outcomes, their direct impact on fine motor coordination or sensory integration remains minimal. The limitation is especially pronounced for activities demanding manual coordination and attentional synchrony, in which conventional interventions prove less effective.

2.2 ADHD Research & Motor Gap

Although ADHD has been extensively studied as a cognitive and behavioral disorder, research on its fine motor control impairments remains insufficient. Prior research indicates that ADHD individuals demonstrate significant deficits in sensorimotor integration and motor planning, which may present as unstable movements, impaired manual coordination, and untidy handwriting [3]. These difficulties adversely influence both academic and professional achievements and diminish individuals’ sense of self-efficacy and confidence in social interactions.

While early work has examined motor training in children with ADHD, comprehensive investigations into fine motor interventions targeting adults are still rare [4]. Using the BOT-2 to assess the general motor competence of adults with

ADHD, significant impairments were reported across most motor domains, yet no marked differences in fine motor abilit. MFNU-based assessments similarly identified motor inhibition and abnormal muscle tone in adults with ADHD, supporting the existence of deficits in fine motor control [5]. Fine motor dysfunction may act as a mediating variable in ADHD, with a notably high comorbidity risk observed in amblyopic populations. Embedding physical movement into cognitive strategy use can aid in integrating internal and external information streams, thus improving overall attentional control effectiveness [6]. This finding lays the theoretical groundwork for incorporating fine motor training into ADHD intervention programs. In conclusion, systematic studies on fine motor interventions for the adult ADHD population are markedly lacking.

2.3 MR for ADHD Rehabilitation

Mixed Reality (MR) refers to an immersive technology combining virtual reality (VR) and augmented reality (AR), allowing for uninterrupted interaction between the physical and digital worlds. In contrast to VR, MR delivers not only complete immersion in virtual environments but also the dynamic integration of digital objects into real scenes, allowing users to receive both real tactile sensations and virtual feedback when performing tasks [7]. Such characteristics endow MR with superior ecological validity and enhanced potential for skill transfer in rehabilitation contexts, especially for interventions demanding fine motor coordination and multisensory processing. Recently, MR technology's use within neurorehabilitation has increasingly been extended to individuals with attentional impairments.

Recently, MR technology's use within neurorehabilitation has increasingly been extended to individuals with attentional impairments. By employing spatial mapping and real-time interactivity, MR systems offer ADHD individuals highly realistic training environments that sustain engagement while improving task attention [8]. The capability of MR to incorporate the tangible physical properties of real objects during interaction has gained interest, enabling users to perceive force feedback and material textures—features that offer notable benefits for hand-eye coordination and movement steadiness training [9]. For fine motor exercises, MR allows participants to handle real tools with superimposed virtual guidance in their visual field, facilitating immediate movement correction and error notification, thereby strengthening motor memory and precision.

MR has further demonstrated potential for cognitive regulation in the context of ADHD rehabilitation. By integrating multi-modal sensory cues into tasks, MR can foster sustained attention in highly interactive environments and support impulse control through real-time feedback [10]. Research has proposed attention training systems that integrate MR with gamified elements, binding rewards to task completion rates, thereby enhancing persistence in ADHD participants [11]. The deployment of MR technologies presents novel avenues for integrating fine motor practice and attention modulation within ADHD rehabilitation programs.

2.4 Role of Reflective Prompts

Reflective Prompts (RP) constitute a metacognitive enhancement technique, generally incorporated into training via questions or cues that prompt users to reflect, assess, and modify strategies following task execution. Rooted in the "metacognitive regulation model" from educational psychology, this approach underscores the capacity of individuals to oversee and adapt their learning processes [12].

Recently, RP has been increasingly adopted in digital intervention design, with empirical validation especially evident in VR and gamification-based platforms. For instance, in the VR intervention system developed in [13], post-task verbal feedback and self-assessment modules were added, prompting users to respond to questions like "What changes did you observe this round?" and "Could you accomplish this with an alternative strategy?", leading to marked gains in strategy transfer and self-efficacy after training. RP guidance can foster greater error tolerance and enhance individuals' motivation for corrective action. Incorporating prompt reflection cues into fine motor training helps mitigate the adverse emotions associated with task failure, encouraging users to persist in learning rather than withdraw [14]. Such an approach is especially crucial for ADHD adults with a predisposition toward emotional regulation difficulties. Combining RP strategies with VR training yields a "metacognitive-enhanced interactive model," which enhances bodily feedback awareness during operations and stimulates strategic reasoning cognitively, thus serving as a bridge between attention control and skill mastery.

3 SYSTEM DETAILS

3.1 Math statements

Based on the results of preliminary user research, the study developed EMLatte, an immersive latte art training system, using the Apple Vision Pro headset and the Unity 3D engine to construct a virtual interactive environment that integrates real-world operations with digital prompts. The system fully leverages the Vision Pro's strengths in spatial recognition and environmental integration, delivering real-time cues on operational rhythm and intelligent feedback on movement stability through pre-recorded instructional videos and multimodal feedback mechanisms. An integrated camera synchronously captures the interactions between users' hands and the tools, with real-time action recognition and dynamic correction performed via the OpenCV image recognition algorithm to ensure training accuracy and responsiveness.

3.2 Virtual environment presentation

3.2.1Task Structure and Interface Comprehension

Before the formal training begins, the EMLatte system offers users an immersive task tutorial and interface guidance process to help them understand the basic logic of latte art operations and the system's interaction mechanisms. Once users don the Vision Pro and enter the virtual environment, they are immersed in a highly realistic coffee workstation scene, with a first-person instructional video filmed by a professional barista embedded at the center of their view to enhance observational immersion and imitation efficiency. The system interface includes multiple cue zones to guide users in gradually building task comprehension: a horizontal arrow at the top indicates the ideal landing spot for the milk foam; a vertical arrow on the left signals the tilt angle for the cup held in the left hand, accompanied by dynamic text instructions; a stage bar at the top identifies the current training phase; and RGB color bands at the edges of the display provide real-time feedback on pouring speed—green for optimal flow, yellow for slightly slow, and red for too fast.

EMLatte incorporates a dedicated reflective voice-prompt feature, prompting users to answer aloud two questions: "Do you fully comprehend the functions of each section in the interface?" and "Can you develop an initial grasp of the latte art workflow based only on the instructional interface?" Based on the user's answers, the system assesses their initial cognitive level and then configures tailored parameters for subsequent training stages.

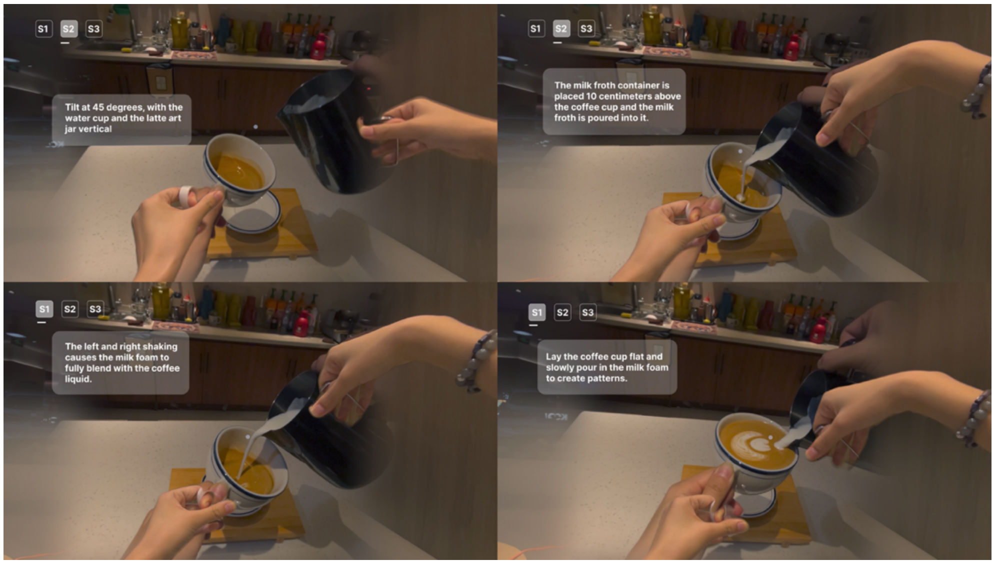

Figure 2: Step one task teaching and interface guidance process virtual reality scene diagram

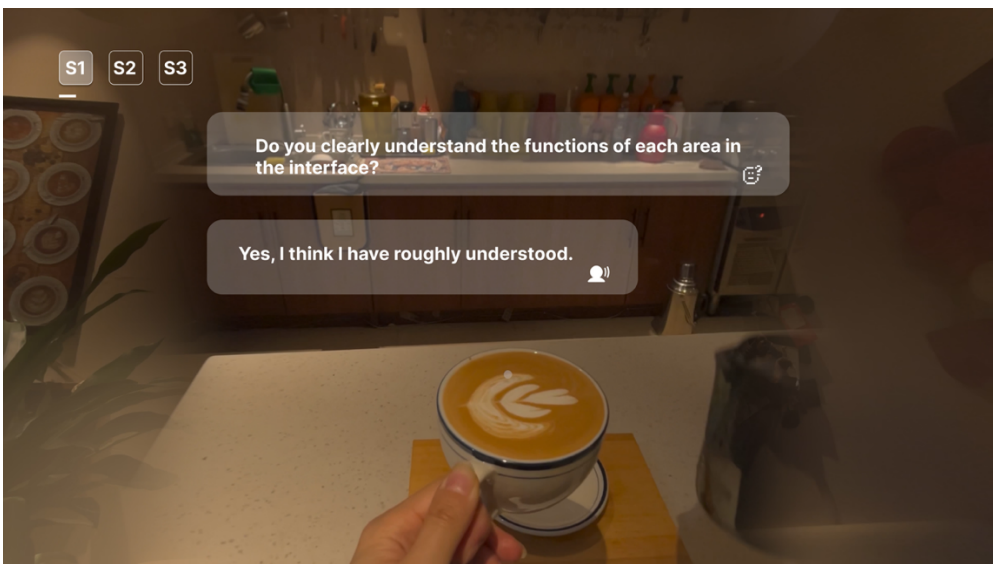

Figure 3: Reflection prompt function in the task structure and interface understanding stage

3.2.2Cognitive Transfer through Simulated Practice

After mastering the basic steps of latte art, the EMLatte system guides users into the imitation learning phase, where they practice synchronously with tools in hand to form an initial memory of movement rhythm and operational paths, thereby reducing psychological pressure and cognitive load during actual performance. The system uses a three-dimensional panoramic motion demonstration video, accompanied by spatial guidance arrows and textual prompts, requiring users to hold an empty coffee cup and milk pitcher to simulate the latte art process shown in the video. This stage draws on the “proxy enactment” method from embodied cognition strategies, emphasizing the transfer of actions from observation to reproduction as a critical step in transitioning from bodily cognition to skill mastery.

EMLatte delivers its instructional material via a 360-degree panoramic view, integrated with spatial guidance cues, enabling users to replicate critical operational actions with precision. During this process, the system also prompts users to provide reflective verbal responses to deepen their intrinsic understanding of the task. Users are required to answer three questions: “Can you describe the purpose of each step in your own words?”, “Can you complete the entire process without relying on the video?”, and “Which step do you currently find the most challenging?”. All voice responses are converted to text and archived in the system’s backend database, serving as the basis for customizing training pathways and adaptively modifying task difficulty.

Figure 4: Step two cognitive transfer simulation training virtual reality scene diagram

3.2.3Embodied Latte Art Practice

The final phase involves an embodied practice session with real liquid participation, marking the commencement of formal latte art training.

At the initial alignment stage, the EMLatte system projects semi-transparent guiding patterns onto the coffee surface, helping users position the milk jug accurately over the intended drop point. The top horizontal arrow guides the spatial placement of the milk foam, and the left-side arrow indicates the tilt of the cup held in the left hand. The guiding line changes to green, indicating “ready,” only when both positioning and angle conform to set standards; if the deviation surpasses the acceptable range, red arrows immediately indicate the correction direction. Upon initiation of pouring, the system tracks the milk flow rate and uses RGB color strips along the screen frame to provide instant feedback: green signifies optimal speed, yellow indicates a slight slowdown, and red denotes excessive speed. On the left panel, textual prompts display the permissible pitcher angle range, paired with rhythmic audio guidance to support the development of a steady pouring tempo. In the pattern-design stage, the system increases the luminance of guiding lines, steering users to manage milk flow direction and maintain a steady wrist position. When the pattern strays noticeably from center alignment, a flashing red arrow at the top signal’s correction, and the left arrow helps refine the cup’s tilt. EMLatte conducts real-time comparisons between the user's action path and benchmark models, offering continuous visual cues to maintain attentional focus and rhythmic stability throughout the embodied practice. Every action is logged in real time, creating quantitative data to inform each user's personalized training progression.

After the session, an automated scoring dashboard appears, offering quantitative assessments based on three criteria: pouring flow rate, hand positioning angle, and design stability. Users are further guided to answer three reflective prompts: "At which stage did you excel most?", "Do you comprehend how score variations relate to your operational behavior?", and "Would you feel sufficiently confident to execute a latte art session independently?". By merging instant performance feedback with reflective questioning, this phase establishes a complete training loop, enhancing cognitive regulation and deepening operational comprehension.

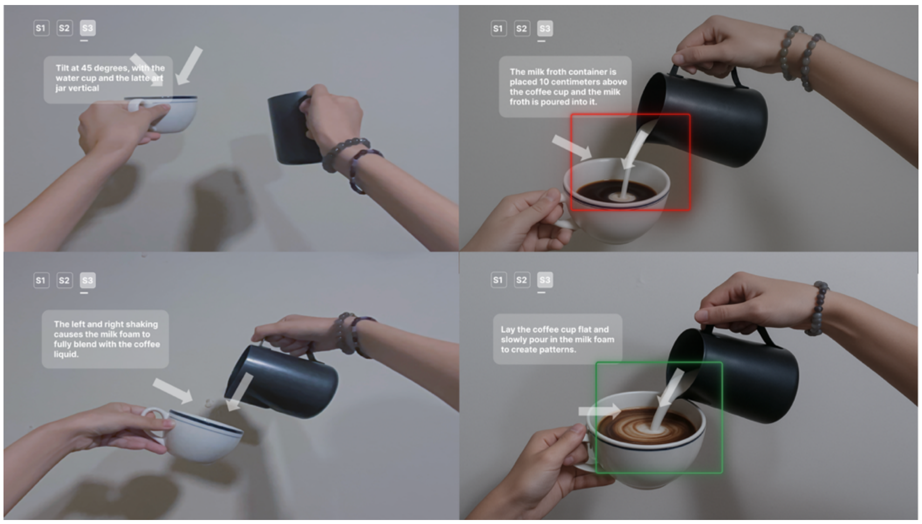

Figure 5: Step three embodied practice latte art virtual reality scene diagram

3.2.3.1 Level Design

The latte art training process in the EMLatte system is divided into six progressive tasks, each corresponding to a typical latte art pattern: basic heart, layered heart, tulip, leaf, swan, and embossed tulip (as shown in Fig. 6). The training path follows a step-by-step instructional logic from simple to complex, progressively enhancing users' abilities in pattern control and movement stability.

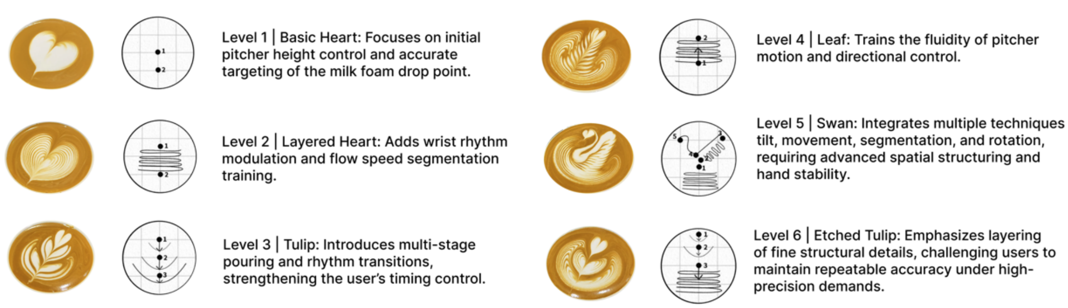

Figure 6: The completion effect diagrams of the six phased tasks and their training significance

3.3 Technical principles

3.3.1Virtual environment presentation

The virtual scenario of the system is built with the Unity 3D engine and implemented on the Vision Pro spatial computing platform, enabling a stable and immersive three-dimensional interface for interaction. The environment constitutes a mixed reality (MR) interactive framework that seamlessly merges real-world sensory perception with virtual data, overlaying interactive 3D elements onto an actual coffee workstation using spatial mapping techniques. It enables users to retain their perception of the physical environment while intuitively manipulating virtual visuals, prompts, and feedback systems integrated into the real-world setting.

3.3.2Virtual environment presentation

The image recognition and motion parameter analysis module in the EMLatte system was developed using the OpenCV 4.9 framework and runs natively on the Apple Vision Pro, ensuring real-time image processing and stable data response. It focuses on detecting and calculating three key variables during operation: the tilt angle of the milk pitcher, the flow speed of the milk foam, and the vertical distance between the pitcher tip and the coffee surface. To enhance robustness, the module employs a multithreaded asynchronous architecture combined with edge-optimized strategies, enabling reliable performance even under challenging lighting conditions or movement disturbances.

Tilt angle recognition is performed using the Hough Line Transform. The system first applies edge detection to extract high-gradient regions along the outer contour of the milk pitcher, then uses a line detection algorithm to identify its principal axis. The angle between this axis and a horizontal reference line is calculated to determine the current tilt state. To reduce the risk of misjudgment caused by anomalies in single frames, the system applies a sliding time window mechanism that performs weighted smoothing on the angle data across consecutive frames, improving both stability and continuity of recognition.

$$\theta_{tilt} = \arctan\left(\frac{y_2 - y_1}{x_2 - x_1}\right) - \theta_{ref}$$

Flow speed estimation is performed using the frame differencing method combined with color masking in the HSV color space. The system targets the white milk foam as the region of interest, generating a binary mask through HSV conversion and calculating the rate of change in the pixel area of this region across consecutive frames. After unit conversion, the resulting rate is mapped to a speed category, classified into three levels: green for optimal speed, yellow for slightly slow, and red for too fast, with feedback provided to the user in real time.

$$v_{flow} = \frac{A_t - A_{\{t-\Delta t\}}}{\Delta t}$$

$$V_{real} = k \cdot v_{flow}$$

Tip-to-surface depth estimation is achieved through the combined processing of depth maps and RGB images provided by the Apple Vision Pro. The system first uses a template matching algorithm on the RGB image to precisely locate the tip of the milk pitcher, then extracts the corresponding real-time depth value from the depth map at that pixel. The average depth of the coffee surface is obtained using background modeling, morphological filtering, and contour detection. Subtracting the two values yields the real-time vertical distance between the pitcher tip and the liquid surface, which is then used to drive the system's visual guidance and interactive feedback mechanisms.

$$d_{\{tip-surface\}} = D_{\{tip\}} - D_{\{surface\}}$$

4 METHODS

4.1 Participants

In the preliminary phase, six adult participants with ADHD (four men and two women; mean age ±1.83) were recruited through social media advertisements and outpatient clinics. In the later phase, 23 additional adults with ADHD (13 men and 10 women; mean age ±2.17) were recruited via the same channels to participate in the system effectiveness evaluation. Upon completing the experiment, participants received compensation at an hourly rate of 60 RMB. All participants had been formally diagnosed by a licensed psychiatrist as meeting the DSM-5 criteria for attention deficit hyperactivity disorder. None had modified their medication regimen or initiated new behavioral therapy within one month before the study, in order to minimize substantial symptom fluctuations during the intervention. Written informed consent was obtained from all participants, who were free to withdraw at any point. The study was conducted with approval from the ethics committee of the local university.

4.2 Product development phase

The study adopted a mixed approach combining questionnaires and semi-structured interviews. The questionnaire (see Appendix 1) collected participants' self-reported information in the following areas: (1) difficulties in attention regulation; (2) perceptions of fine motor skills, such as confidence levels and frustration when performing daily tasks requiring precise hand movements; (3) self-assessed emotional state; and (4) acceptance of digital technology. This was followed by semi-structured interviews centered on several pre-designed guiding questions, such as "What situations challenge your attention the most in daily life?". All questionnaire scores and interview transcripts were organized and analyzed: quantitative data were processed using descriptive statistics, while qualitative feedback was coded to identify recurring themes. The findings directly informed adjustments to the VR system design, particularly in refining details of the interaction process.

4.3 interventional trial

Each participant completed an individual two-week VR latte art training intervention. The schedule consisted of three sessions in the first week and three sessions in the second week, for a total of six sessions [15]. Each session lasted about 60 minutes and included: (1) Warm-up – a five-minute free exploration of the virtual environment to become familiar with the day's exercises [16]; (2) Training tasks – step-by-step practice following the six-stage process described in the system specifications, with one to two steps covered per session depending on progress [17]. If a participant failed to meet the preset criterion for a step (for example, three consecutive pattern matching scores below 80%), the system repeated that step in subsequent sessions until it was mastered before proceeding [18]; (3) Break and feedback – a short rest after every 20 minutes of training, during which the researcher checked comfort levels (e.g., dizziness or fatigue) and adjusted headset fit or display settings to ensure safety [19,20,21]; (4) Summary and reflection – before ending the session, the system guided participants through a set of reflective prompts, and the researcher conducted a brief interview, asking them to summarise in their own words what they had learned and the difficulties encountered. The schedule balanced training intensity and user experience, with most sessions arranged during periods of optimal attention, typically in the morning.

Within one week after the final session, participants repeated the same attention and fine motor tests as at baseline to assess post-intervention effects [22]. Key quantitative measures included omission error rate on the CPT (to assess improvements in sustained attention), mean reaction time, completion time for the Nine-Hole Peg Test, and number of taps in the finger-tapping test over 10 seconds [23]. Pre- and post-intervention measures were compared using paired t-tests or non-parametric tests to determine significance.

For qualitative evaluation, each participant took part in a 30-minute in-depth interview after the intervention, covering topics such as subjective impressions (immersion, enjoyment), perceived changes in attention and emotion, feedback on the reflective prompts module, and overall system usability[24]. Interview recordings were transcribed and analysed thematically, with recurring themes and representative viewpoints identified. In addition, training system log data (e.g., time spent on each step, number of errors) were recorded to support interpretation of user performance.

5 RESULTS

5.1 User research phase

The questionnaire results (n = 23) indicated that adult participants with ADHD experienced pronounced difficulties in attention and self-regulation. More than 82.6% scored 4 or above on the "easily distracted" item, and 80.0% gave high scores for "mind-wandering during tasks." In contrast, low scores were reported by 69.6% and 73.9% of participants on the items "aware of becoming distracted" and "able to refocus after distraction," respectively, reflecting weaknesses in attention regulation and re-focusing ability. In the fine motor and hand–eye coordination domain, approximately 78.3% reported "poor hand coordination" and 73.9% reported "difficulty with small tool operations," while low scores were recorded by 65.2% and 69.6% on the positive items "good hand–eye coordination" and "good finger control," respectively. Regarding emotion and mindfulness, 73.9% often felt anxious or tense, and 65.2% reported difficulty entering a flow state, with fewer than half indicating that they could remain focused on the present or maintain high emotional awareness. Technology acceptance was generally high: 91.3% expressed curiosity toward new technologies, and 95.7% considered VR an enjoyable way to learn, although 39.1% voiced concerns about potential discomfort from VR use. These findings suggest that system design should address deficits in attention control, fine motor stability, and emotional regulation by enhancing multimodal guidance and stepwise training, while optimising hardware comfort and visual load to improve sustained engagement and overall user experience.

Semi-structured interviews revealed that adults with ADHD were generally susceptible to environmental distractions in daily life, particularly in situations with high noise levels, multiple conversations, or complex multi-step tasks. Most participants reported feeling nervous during activities requiring precise hand movements, such as writing, crafting, or decorative cooking; this nervousness often led to hand tremors or inaccurate movements, which in turn reduced their confidence in completing the task. Several participants noted that, when facing complex tasks, the absence of step-by-step prompts and immediate feedback often resulted in premature abandonment. Conversely, when tasks were broken down into clear sub-steps with accompanying visual or auditory cues, they found it easier to stay focused and achieve their goals. On the emotional side, some reported strong negative reactions to task failure and a tendency to experience frustration, although others said that immediate positive feedback during training significantly alleviated such emotions and motivated them to continue. In terms of technology use, most participants were open to trying MR or VR systems and felt that immersive contexts helped block out external distractions, but a few expressed concerns about potential eye strain or dizziness from prolonged headset use. These findings underscore the importance of incorporating structured task flows, immediate multimodal feedback, and emotional support mechanisms into the design to foster focus, confidence, and sustained participation.

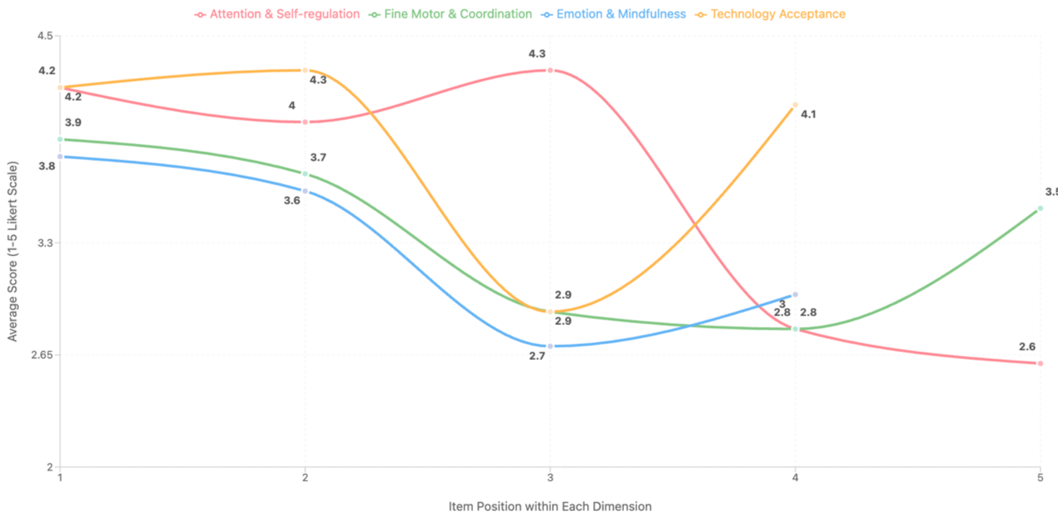

Figure 7: Average Score Trends Across Dimensions in Pre-System Design Questionnaire

5.2 Product usability test results

After completing the two-week EMLatte VR latte art training intervention, participants demonstrated positive changes in both attention regulation and fine motor execution. Quantitative results showed that the CPT omission error rate decreased by an average of 27.8% compared with baseline, and mean reaction time was reduced by 312 milliseconds, indicating improvements in sustained attention and processing speed. In the Nine-Hole Peg Test, completion time was significantly reduced by an average of 5.2 seconds; in the finger-tapping test, the number of taps within 10 seconds increased by 13.5%, reflecting enhanced stability and rhythm in hand control. The system's automated scoring also indicated that over 78% of participants had reached the "proficient" threshold (⩾85%) in pattern matching, flow control, and tilt angle dimensions by the later stages of training, with performance showing a trend toward stability.

Post-intervention in-depth interviews provided further insight into participants' subjective experiences with the system's interaction design. Most reported being able to enter a deep state of focus during training and felt that the immersive setting helped eliminate external distractions and foster a clear sense of goal orientation. Several participants highlighted that the system's rhythmic audio cues and spatial guidance directly aided in establishing movement rhythm and maintaining stable hand posture, while the imitation training stage helped "build muscle memory" and reduce nervousness during real operations. Notably, the embedded reflective voice prompts were widely recognized as "helping clarify the purpose of each step" and "improving the sense of control over the entire process." Feedback on the system's real-time guidance was also largely positive, with participants describing it as "immediate" and "clear," which boosted their confidence and ability to make adjustments during tasks.

Some participants offered suggestions for improvement after the experiment, such as addressing delays in pattern recognition feedback for certain designs and enhancing the comfort of the headset during prolonged use. These comments were documented in the system logs and research notes as key references for future design iterations. System behavior logs also revealed a clear learning curve: the average number of errors per session dropped from 4.3 to 1.2 over the six training sessions, average time per practice decreased from 92 seconds to 61 seconds, and the time taken to respond to reflective prompts was reduced from 18 seconds to 9 seconds, suggesting that task understanding became progressively internalized.

Overall, the EMLatte system demonstrated strong potential for supporting attention regulation, improving fine motor skills, and fostering task comprehension and self-reflection, validating the application value of immersive embodied interaction interventions in the context of adult ADHD.

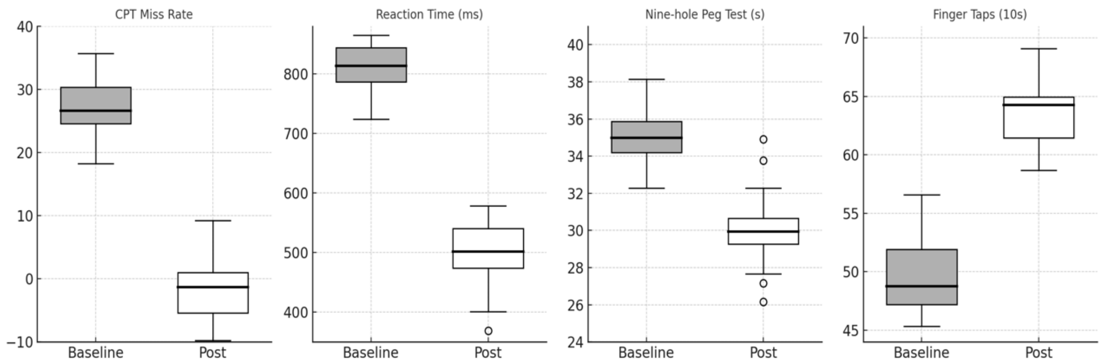

Figure 8: Performance Changes in CPT Miss Rate, Reaction Time, Nine-hole Peg Test, and Finger Taps Before and After VR Latte Art Training

6 DISCUSSION

The EMLatte system proposes and validates a new paradigm for fine motor training in adults with ADHD, integrating virtual reality with embodied interaction. Findings indicate that the system significantly improves attention focus, enhances movement rhythm control, and promotes metacognitive reflection, demonstrating the potential and feasibility of immersive technologies as a non-pharmacological intervention pathway [25, 26, 27].

Post-training improvements in attention highlight the advantages of immersive environments in controlling external distractions and reinforcing internal goal orientation. Most participants explicitly stated in interviews that it was “easier to stay focused than with traditional tasks” and that “there was only one goal in sight.” This feedback aligns with existing literature on the role of VR in enhancing attentional control. Significant reductions in CPT omission error rate and reaction time further support, from an objective perspective, the effective engagement of attentional resources. Improved performance in the Nine-Hole Peg Test and the finger-tapping test suggests that the movement rhythms and path memories established in the virtual environment successfully transferred to real-world operations. Notably, the imitation learning stage was repeatedly described as “the most critical part” by participants, supporting the core value of proxy enactment as an embodied cognition training method, in which initial motor schemas are formed with lower cognitive load, thereby reducing frustration and enhancing confidence [26, 27, 28].

The embedded reflective prompt mechanism was not only highly valued in participants’ subjective reports but also showed measurable behavioral effects. The gradual decrease in the time taken to respond to reflective questions suggests that participants’ understanding of the training process became increasingly clear, and their grasp of the causal relationship between task structure and performance feedback progressively strengthened. This mechanism enhanced self-monitoring and strategic adjustment abilities, addressing the often-overlooked metacognitive dimension in ADHD training and providing theoretical support for improving cognitive–motor integration [29,30].

Despite the system's overall strong performance, some limitations remain. Several participants reported slight delays in pattern recognition, potentially related to algorithm optimization or device frame rate. Prolonged headset use also led to mild fatigue in some cases, suggesting that future iterations should further improve hardware comfort and allow for flexible pacing adjustments. The small sample size limits the generalizability of the results, and larger-scale studies are needed for further validation. Future research could incorporate control groups and delayed post-tests to better assess retention effects and the breadth of skill transfer [31].

As an intervention tool combining cognitive training, embodied operation, and reflective regulation, the EMLatte system demonstrates the integrative potential of cross-modal learning and cognitive rehabilitation. It offers adults with ADHD an engaging non-pharmacological training option and provides a reference model for expanding the application of digital therapeutics in fine motor skill interventions [32].

7 CONCLUSION

This study proposes and preliminarily validates an immersive virtual reality intervention paradigm that uses simulated latte art tasks to provide adults with ADHD a non-pharmacological, game-like platform for training attention and fine motor control. Without reliance on medication, this immersive approach offers a new possibility for enhancing the daily functioning of individuals with ADHD. While VR interventions are not universally effective for every patient, and careful consideration of long-term outcomes and individual differences remains necessary, the design of this VR latte art training system—together with early user feedback—suggests that combining real-world skill practice with virtual environments can serve as a valuable complement and extension to ADHD interventions.

8 FUTURE WORK

In the future, we plan to conduct rigorous controlled experiments with a larger sample to evaluate the intervention effects of the VR system, including objective measures of attention and functional outcome indicators. We will also continue gathering user feedback to iteratively improve the system—for example, expanding the variety of latte art patterns to increase training engagement, and enhancing headset comfort to reduce dizziness, thereby promoting rehabilitation training for adults with ADHD.

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A APPENDICES

In the appendix section, three levels of Appendix headings are available.

A.1 General Guidelines (AppendixH2)

1. Save as you go and backup your file regularly.
2. Do not work on files that are saved in a cloud directory. To avoid problems such as MS Word crashing, please only work on files that are saved locally on your machine.
3. Equations should be created with the built-in Microsoft® Equation Editor included with your version of Word. (Please check the compatibility at http://tinyurl.com/lzny753 for using MathType.)
4. Please save all files in DOCX format, as the DOC format is only supported for the Mac 2011 version.
5. Tables should be created with Word’s “Insert Table” tool and placed within your document. (Tables created with spaces or tabs will have problems being properly typeset. To ensure your table is published correctly, Word’s table tool must be used.)
6. Do not copy-and-paste elements into the submission document from Excel such as charts and tables.
7. Footnotes should be inserted using Word’s “Insert Footnote” feature.
8. Do not use Word’s “Insert Shape” function to create diagrams, etc.
9. Do not have references appear in a table/cells format as it will produce an error during the layout generation process.
10. MS Word does not consistently allow the original formatting to be modified in the text. In these cases, it is best to copy all the document’s text from the specific file and paste into a new MS Word document and then save it.
11. At times there are font problems such as “odd” stuff/junk characters that appear in the text, usually in the references. This can be caused by a variety of reasons such as copying-and-pasting from another file, file transfers, etc. Please review your text prior to submission to make sure it reads correctly.

A.1.1 Preparing Graphics (AppendixH3)

1. Accepted image file formats: TIFF (.tif), JPEG (.jpg).
2. Scalable vector formats (i.e., SVG, EPS and PS) are greatly preferred.
3. Application files (e.g., Corel Draw, MS Word, MS Excel, PPT, etc.) are NOT recommended.

4. Images created in Microsoft Word using text-box, shapes, clip-art are NOT recommended.
5. IMPORTANT: All fonts must be embedded in your figure files.
6. Set the correct orientation for each graphics file.

A.2 Placeholder Text

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