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# Neurofeedback Training in Mixed Reality: The T-AttentionGo Framework for Children with ADHD

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## Abstract

Neurofeedback training (NFT) has emerged as a promising intervention paradigm for attention training in children with Attention Deficit Hyperactivity Disorder (ADHD). However, current NFT methods often do not sufficiently motivate active participation and do not leverage positive peer effects. To develop a more effective NFT paradigm, we first conducted an interview to identify challenges in the existing NFT method, from which we derive two key design considerations. We subsequently developed T-AttentionGo, a Mixed Reality-based Team Neurofeedback Training paradigm that supports self-design and cooperative training modalities for children with ADHD. Then we conducted a pilot study. Through objective data analysis and video observation, we initially gained some insights and hypothesized that the self-designed environment and the training mode of task-divided would make the neurofeedback training simpler and more effective.

**Keywords:** Neurofeedback, ADHD children, Attention training.

## I. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder that significantly affects children's cognitive and behavioral functioning [2], primarily manifesting through symptoms such as inattention, hyperactivity, and impulsivity. These symptoms lead to children with ADHD face greater difficulties in cognitive and social activities, which affects their mental health (e.g. self-esteem), social interaction and academic performance [3]. Neurofeedback Training (NFT) has emerged as a promising non-pharmacological intervention for ADHD, demonstrating efficacy in mitigating core symptoms associated with the disorder [5, 4 ]. It provides real-time feedback for trainer to intuitively understand and manage their brain function [1]. Despite demonstrating significant potentials, the practical implementation of NFT faces numerous challenges. The optimization of training efficacy is the central focus of this study.

To explore a more effective NFT paradigm, therefore, we first conducted a semi-structured interview to understand the key challenges in current NFT for children with ADHD. In order to overcome these challenges, we combined psychological theories to design T-AttentionGo - a new neurofeedback training paradigm based on mixed reality , which enables ADHD children to carry out Self-design and cooperative training. The results of the pilot experiment show that this system has received a high popularity. The self-designed environment and the Task-divided training mode may make the NFT simpler and more effective. This new neural feedback training paradigm will make training in line with life, making it easier to accept.

## II. Methodology

### A. *Preliminary Research*

To gain an in-depth understanding of the challenges associated with current NFT methods for children with ADHD, we implemented a multi-stage participant recruitment and interview process. We initially distributed an online survey via social media channels, targeting parents of children with ADHD. A total of 54 valid responses were collected. In addition to the demographic information of the children (e.g. age, gender, time of diagnosis), the survey explored participants' prior rehabilitation experiences, familiarity and preferences regarding NFT, as well as the perceived needs of their families.

Finally, we selected 7 parents to participate in the interview. These parents all have children with ADHD aged 5 to 12, and their children had received at least 3 months of NFT intervention. Additionally, considering the significance of the professional treatment perspective, we also recruited 3 NFT rehabilitation therapists with several years of professional experience. We conducted one-on-one, 90-minute semi-structured online interviews with the 10 participants mentioned above. The interviews began with structured questions to gather basic personal information, followed by the parents describing their experiences with their children's neurofeedback training and providing detailed evaluations. We engaged in in-depth discussions with the parents across seven areas: rapport, emotional, financial, psychological, physical, social, and time. The main interview questions were as follows:

(1) What is your opinion about the neurofeedback training conducted in an institution? How about training at home? (for parents and therapists) (2) What do you think about the effect of neurofeedback on the child/children? (for parents and therapists) (3) what are the main difficulties children encounter during neurofeedback training? (for parents and therapists) (4)Has your child ever participated in neurofeedback training with a peer? How do you think the inclusion of peers affects neurofeedback training?

After the interviews concluded, the researchers summarized and analyzed the responses of the ten participants, ultimately identifying the following three challenges:

**Challenge 1:Short of long-term motivation.** According to the questionnaire results, the content of the games is usually centered around sports themes, such as racing or the tortoise and hare race. Therapists reported that their NFT providers typically do not update or add more diverse game themes.These games usually do not support personalization and expansion. Children easily get bored with the same old game content after few training sessions.NFT trainees are required to block out external distractions and focus their attention on controlling objects in the virtual world continuously. This demand is particularly challenging for children with ADHD, making it easy for them to abandon the training in its early stages. In other words, they need to be ”encouraged” and ”continuously guided” throughout the training. Without this support, feelings of frustration and boredom can lead ADHD children to give up on NFT training easily.

**Challenge 2:Monotonous interaction and lack of involvement.** NFT generally relies merely on video game interactions, which limits the interaction to the computer screen. Some parents reported that their children experienced ”eye strain” after training (P1, P2).This kind of interaction limited to computer screens makes children passively accept game content in the virtual world fixed by developers, lacking a sense of active participation. In addition, the feedback provided by the virtual world is also relatively monotonous and not strong enough, which is unable to fully ignite the enthusiasm of children to participate.

**Challenge 3:Separation from the real world.** Some parents mentioned in the interview that the children involved in the existing neurofeedback training do not feel the people around them, and in the observation of parents, the children are like playing a single game, they just go it alone, and ”score” alone in the absence of cooperation. A mother (p3) reported that her son, who had received four months of NFT training, told her that ”I already know how to control it, and as long as I don’t blink, I can get a high score in the game”. When the trainer finds a ”bug” in the game, the training loses its meaning. In addition, some parents mentioned that although their children performed well in NFT, they could not feel the changes in their school and life.

*B. Conceptual Design*

We combined the research results and finally came up with the conceptual design shown in Figure 1, which consists of four phases:

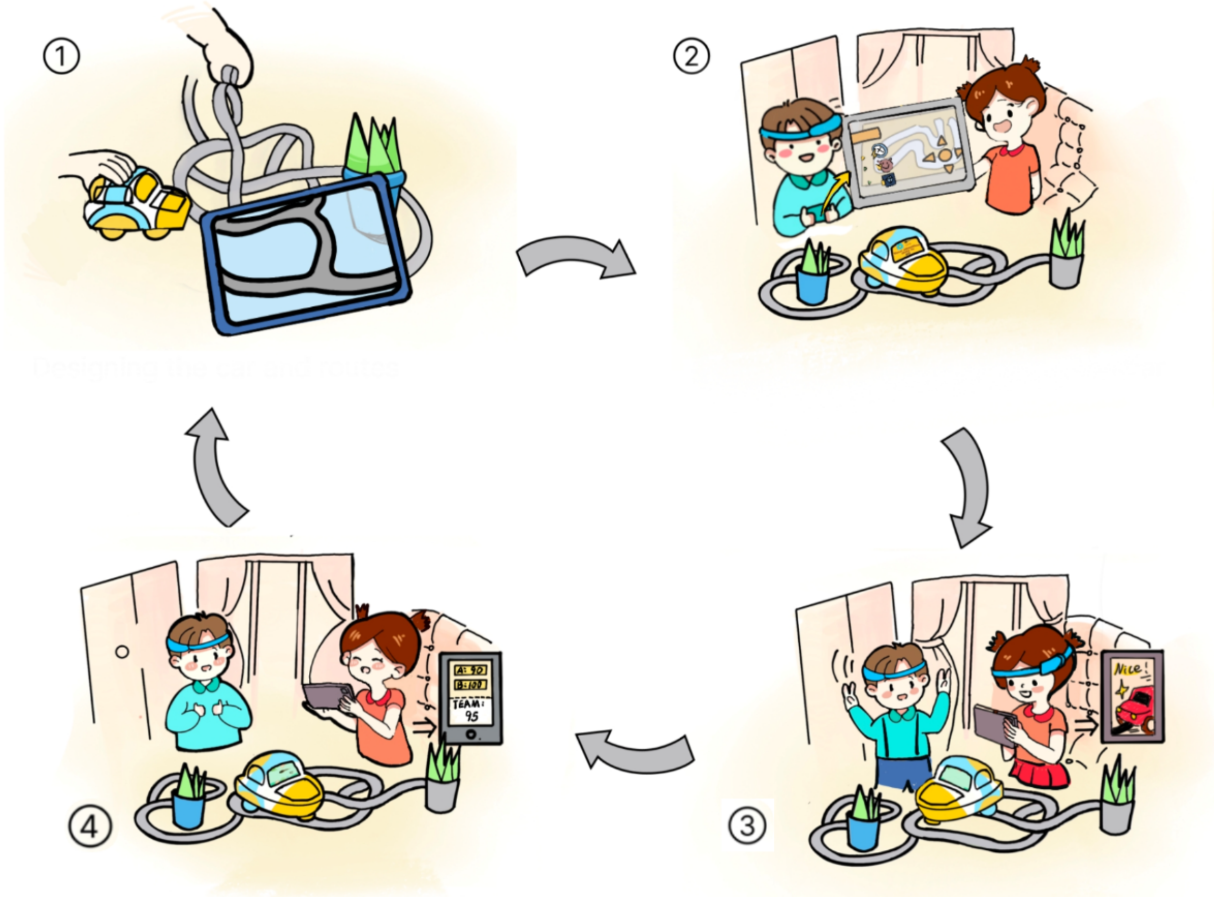

Fig 1: Conceptual Design

**Phase 1 (Path Creation):** NFT participants first create their desired path using adhesive tape, allowing autonomous construction of a multiplayer gaming space. This also allows the two participants to initially acquaint themselves, break the ice. We attempt to create a sense of novelty by building the training environment in this way and maintain children's long-term motivation.

**Phase 2 (MR Scene Activation):** After that, the participants used the MR System to create the scene in the application. This step allowed the children to turn passive into active in the training, increase the sense of participation, and ”carry” their pasting path into the virtual world. And MR Technology allows training to go beyond the computer screen. This medium can better stimulate children’s enthusiasm for participation.

**Phase 3 (Collaborative Training):** In order to make neural feedback training closer to the real life, system allows two participants at the same time for training. We designed two different training modes, collaborative and task-divided, to simulate different social situations. Participants can get multiple feedback, including MR Effects, interactive car speed, and peer language and action, so as to increase the immersion of ADHD children in training and improve their willingness to participate in training.

**Phase 4 (Performance Visualization):** Participants review training metrics (scores/milestones) to assess progress. This process encourages participants to engage in discussions centered around a shared goal (making the car go faster). This will help them gain a sense of accomplishment, which will improve the effectiveness of the training and ultimately contribute to the virtuous cycle of training.

### *C. Implementation*

We propose a neurofeedback training system based on the design of a ‘racing car’ background that is attractive to children with ADHD (Fig.2). The system consists of four parts:

**Self-design Module (A)**: In this module, children engage in self-directed design by using tape to set up a scene (Fig. 3(a)) and selecting a scene theme (Fig. 3(g)). The system then generates a virtual scene based on the physical scene and the selected theme (Fig. 3(b)). Children can freely add relevant thematic elements (Fig. 3(h)) to the scene. All of these elements together form the Self-Design Training Space.

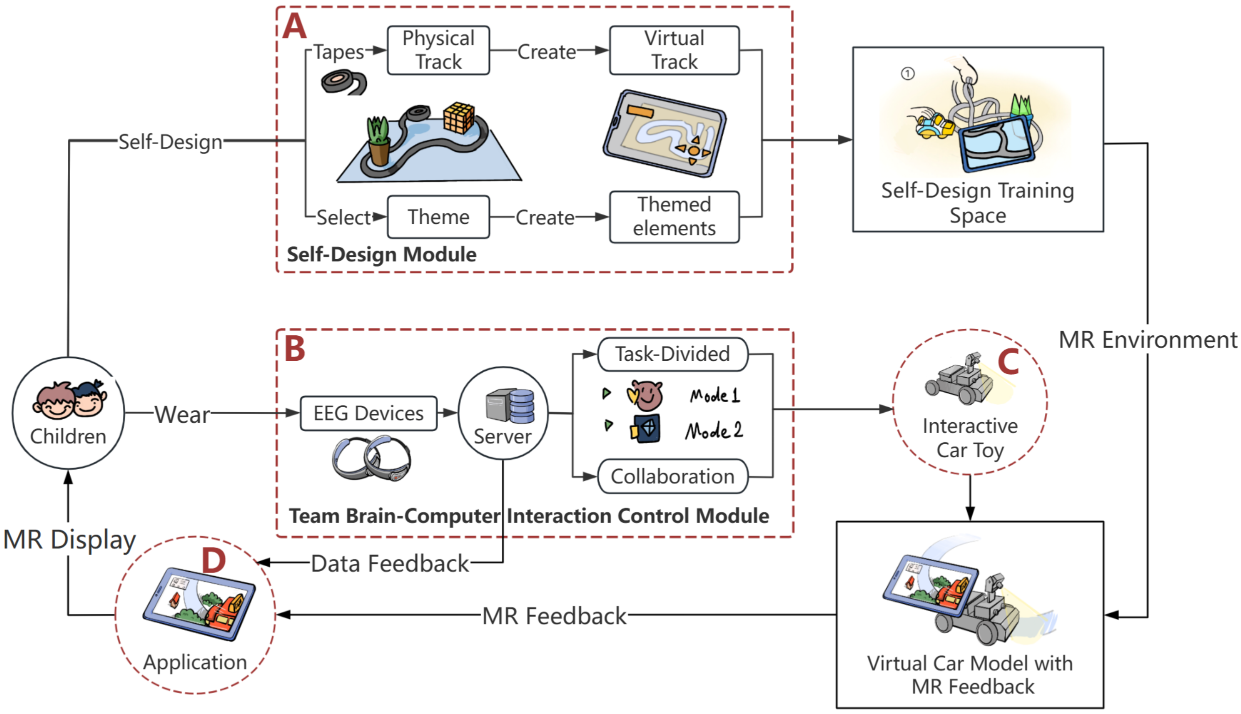


Fig 2: Implementation of the System

**Team Brain-Computer Interation Control Module (B)**: In this module, two Brain Link EEG devices collect attention data in real time and transmit them to the server. The EEG device integrated with the eSense algorithm, can generate attention scores ranging from 0 to 100. It has been proven to be feasible and effective through numerous previous studies. [8, 7, 9, 6] The server processes data with two different control logic, which is consistent with the two cooperation mechanisms designed above (Task-Divided or Collaboration), and outputs the speed value.The speed value is sent to the interactive car toy to change the speed.

**An interactive car toy (C)**: It receives the speed data processed by the server and provides feedback on the attention level by changing the travel speed. At the same time, the interactive car is also used as the binding object and tracking target for the MR Effect in the subsequent application (Fig. 3(d)).

**An Application (D)**: It runs on a phone or tablet and provides convenient neurofeedback to demonstrate the previously constructed Self-design training space (Fig. 3(c)). During the training, the application receives data from the server and displays the concentration of the two participants in real time (Fig. 3(f)). After the virtual car is bound to the physical car, the application also displays different effects (Fig. 3(e)) according to the real-time attention level. These four parts Component NFT System to guide children with ADHD to reach training goals by focusing their attention and working with each other.

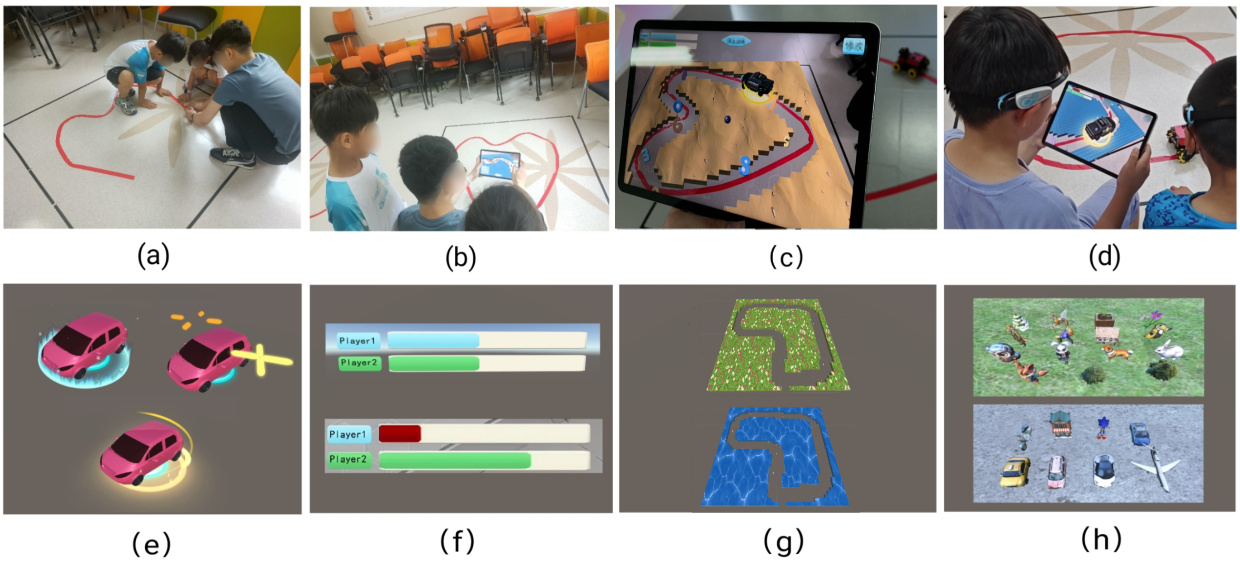


Fig 3: Snapshots of using T-AttentionGo. (a) children and researcher are taping the track,(b) scene modelling using the tablet application,(c)and(d) MR feedback while training,(e) feedback effects on interactive car toy model,(f) the ”Energy Bar”to show real time attention,(g) different scenario models,(h) Relevant elements in the MR space to be added in training.

## III. User Testing and Results

With the assistance of a local hospital, we conducted a pilot study involving 8 children aged 6 to 12. All participating children had been diagnosed with ADHD and had limited prior experience with neurofeedback training. All children and their guardians were informed that all information and data collected during the study would be used solely for research purposes and would not be disclosed in publications.

### A. Test Environment

The user testing was conducted in a spacious, quiet, and brightly lit room at a local hospital. The experimental setup included a Lenovo ThinkBook 16p equipped with an i9-13700 CPU and an NVIDIA 4060 graphics card, a Xiaomi tablet, two Brainlink Lite devices, and an interactive toy car fitted with a Raspberry Pi and camera. To comprehensively record the training process, we positioned a camera in the corner of the room. We tried to minimize potential distractions by reducing the number of unrelated items and personnel as much as possible. During the experiment, all child guardians were situated out of the children's line of sight, with only two researchers accompanying the children to perform the experimental tasks.

### B. Results

The results of the pilot study were derived from feedback provided by the children who participated in the training, observations during the training, and analysis of recorded videos. The participants reported that they really enjoyed this innovative training method, which felt like playing a game, indicating that the system has been very well received by the users. Compared to traditional NFTs, the introduction of self-design allows training content to be tailored to participants' preferences, effectively preventing boredom and helping to sustain long-term motivation.During the self-design process, participants demonstrate more proactive engagement and emotional expression, and they collaborate to create the content of the MR virtual scenes. This process fosters communication and interaction among participants, effectively cultivating their collaborative and social skills. For example, during one experiment, two participants disagreed on which car virtual avatar to choose. One participant wanted to choose the excavator model, while the other wanted to choose the police car model. At that point, one participant suggested, "We have two chances to choose. This time, you can pick the excavator, and next time, I'll pick the police car." The two participants eventually reached an agreement. This example clearly demonstrates that the Self-design mode creates more opportunities for interaction among participants, thereby enhancing their social skills.

During training, as is clearly evident in the video, especially in collaboration mode, children are more likely to view the training as a game and an interactive experience rather than a task. Having a peer join the program clearly helps boost the motivation of ADHD children to participate in training and enhances their social skills, ensuring that the benefits of NFT are effectively applied in real-life situations. However, in Task-divided mode, because of inconsistencies in tasks, children play different roles during training, which makes disputes more likely to arise and has a negative impact on the training process.

After the experiment, many participants expressed the desire to experience it again, indicating that the training did not bore the children. On the contrary, many participants viewed the training as a novel game and expressed a willingness to engage in this training over the long term.

## IV. Conclusion

First, this study used interviews to identify the challenges currently faced by ADHD children during NFT. We then designed an NFT system based on MR that supports self-designed and multi-player training. Subsequently, we conducted a pilot study to assess acceptability of the system and explore the feasibility of incorporating different design patterns and collaboration methods into NFT for ADHD children.

Based on feedback from the children who participated in the training and observations by researchers, we found that the self-design and multi-player NFT paradigms were well-received by ADHD children. This provides valuable insights for future research and practice, helps advance the development of NFT for ADHD children, and provides inspiration to researchers in related fields.

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