An AR Sandbox as a Collaborative Multiplayer Rehabilitation Tool for Children with ADHD

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ABSTRACT

Neurofeedback systems have been increasingly utilized in recent years for the treatment of ADHD. However, the disease-specific characteristics and the training motivation are only taken into account to a limited extent, especially for the therapy of children. Inspired by previous research in projector-based AR, we propose a new AR-based multiplayer game with BCI and haptic feedback for the therapy of children with ADHD. We evaluated our approach in an explorative user study with seven domain experts with different backgrounds related to the topic. The results show a harmonious combination of different technologies and that the multiplayer approach and the haptic aspects of the game are suitable and motivating to complement existing therapy methods. The results create an essential basis for further development of patient-oriented neurofeedback systems in ADHD therapy.

KEYWORDS

Brain-Computer-Interface, Multiplayer Game, Tangible Interaction, ADHD, Children

1 Introduction

ADHD (Attention deficit hyperactivity disorder) is a mental disorder that is present at any age. It affects 5% of children and adolescents worldwide and is the most common psychiatric disorder among children between 8 and 14 years of age [15], the target group addressed in this work. Especially children often have problems with learning and social life due to the symptoms. ADHD often is expressed by a low attention span, impulsivity and, in case of additional hyperactivity, by physical restlessness [27]. Patients show a low frustration tolerance, low self-esteem and varying frequently in mood. There are also strengths in addition to the deficits that result from ADHD, such as hyperfocus, in which the affected persons fall into a steady flow state, allowing them to work exceptionally focused [18]. Patients are often hypersensitive, in need of harmony, show a high degree of empathy and a clear sense of justice. Understanding weaknesses and strengths is necessary to develop a training adapted to these characteristics that allow the user to train in a focused way and at the same time promotes fun without creating frustration points. This changes the focus from weaknesses to strengths [18].

In clinical therapy, Brain-Computer-Interface (BCI) Training is used as a drug-free therapy for children with ADHD. Electrodes are attached to the child's head by a cap. By measuring the activity in the brain regions and providing corresponding feedback on a screen, a feedback loop is created that enables to learn how to focus over a more extended period of time. The training is usually done once a week in up to 60 sessions within 30-60 minutes [13] in a clinic under supervision. In most BCI trainings, the child sits still and uses them in a single user mode. This offers optimization of functional cognitive training [12] but is limitedly adapted to the needs of children with ADHD.

Our goal is to develop an approach that playfully integrates movement and haptics into BCI training, addresses social skills and creates a calm atmosphere to promote focus. In the long-term, this may promote motivation in training and thus its effectiveness. As a starting point, we have developed a game prototype for a god mode simulation based on the AR Sandbox [28]. The landscape projected on the sand can be changed by changing the height of the sand. Sand is a medium that most people know from their childhood, offers room for creativity and enjoyment and little fear of contact. We have combined the interaction with the AR-Sandbox with two BCI headsets and an eye-tracking device so that it can be played collaboratively (Figure 1) with therapists or other children.

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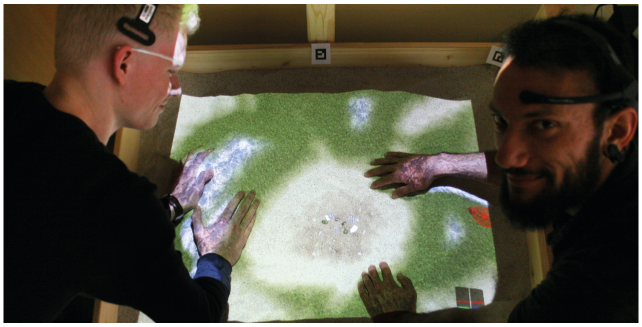

Figure 1: Sandbox with BCI in a game situation

We focused on the following research questions:

- (Q1): How does the game affect users and how is one's contribution to game success perceived?
- (Q2): How do the BCI control, the eye-tracking and the haptic component of sand work individually and together?
- (Q3): How is the multiplayer mode perceived in a complex technical context with haptic elements and how does the role distribution affect the players?
- (Q4): Is a multiplayer game with eye-tracking, BCI and haptic elements suitable for use and motivation and integrable into therapy for children with ADHD?

The contributions of this work are a prototypical development and systematic evaluation of a multiplayer model with haptic components within a neurofeedback game in the field of ADHD therapy. The results of an explorative qualitative expert study support the potential motivational effect for children with ADHD and the suitability for use in therapy. Based on this, we show possibilities of how the approach may be used in current therapy.

In the following, we first describe current research and the basics of the development of the prototype. Second, we show the concept and technical implementation. Third, the evaluation and results are presented and critically discussed, in particular, concerning the necessary steps for integration into a clinically applicable therapy system.

2 Related Work

The use of digital games supports the concentration of children with ADHD [4]. Digital games help to train focus control, as an EEG comparison in a study on the influence of BCI video games on children with ADHD shows [2]. They support the motivation for training [23]. These games are classified as Serious Games, which pursue a goal outside the game [7], such as therapy [21] or education [6].

Various ADHD training games are commercially distributed. Aligned with the game aspect of the training is ‚Focus Pocus' [21]. The measured EEG waves are used to influence a game on the computer. With a similar approach, the game ‚Harvest Challenge' was used to show the increased brain wave activity [2]. ‚Plan-It Commander' includes the training of everyday skills, like time management or organizational skills [4].

In the Social Cognitive Theory [1], one's behavior is developed by observing others. We suggest considering this approach for concept development. Research results show that multiplayer games are suitable approaches to integrate social learning [29]. Both collaborative and competitive multiplayer scenarios are motivational and performance-enhancing compared to single-player scenarios [3]. The combination with a tutor model, in which an experienced person explains things to a less experienced person also supports the use of a multiplayer. Often negative reinforcement is used in BCI games. Positive reinforcement as a behavior enhancing element promotes intrinsic motivation and is better suited to help players regulate brain activity [24]. This effect shall also be used in this work.

The AR Sandbox [28] has been used in various scenarios. It is a suitable tool for supporting learning at school due to its haptics and physical demonstration [26]. Also, the transfer of the sand surface into a digital game world on the screen [5] or in VR [10] and a biofeedback controlled application to support meditation [25] was developed. Haptic interaction demonstrated to be particularly supportive and creates a direct feedback loop [14].

In therapy, EEG headsets with high measurement accuracy are used (e.g. Nielsen). Despite optimized application, fit and fixation have to be aligned on the head. Technically reduced headsets (e.g. NeuroSky) with higher usability are available for games in combination with computer or mobile devices. Their intensity of alpha and beta frequency of brain waves characterizes focus and relaxation [11], the basis for deriving the player's focus.

Haptic feedback is used for learning BCI control using a vibrotactile transducer [17]. Dhillon et al. [9] propose the combination of EEG signals and eye-tracking as a method of interaction. However, this could lead to visual fatigue. Therefore, the use of haptics can be a complementary component.

3 Prototype

Initially, we analyzed restrictions and requirements based on literature and interviews with experts. The mentioned strengths of children with ADHD like emotional sensitivity and empathy should be addressed by a collaborative multiplayer mode. There should be as few frustration points as possible. Interactions, goals and tasks should be constructive to prevent termination, maintain motivation and allow flow. Haptic interactions and movement should be enabled, but a calm training situation should be created to allow focus. Usability and flexibility should be kept as high as possible despite high technical use.

3.1 Game Concept

The concept development is based on designing a game that is fun for the target group instead of extending existing training with game elements or mechanisms. The goal of such an approach is to create an enjoyable activity on its own [8]. The conceptual decisions were made taking into account the symptoms of ADHD patients, including feedback from psychologists working with children with ADHD in therapy.

We created a god mode simulation with city-building game elements. A god mode simulation is a strategy game and played predominantly in real-time, like 'Black & White' [19]. The player assumes a god-like role and is responsible for a world, its population and its development. City-building games have a simulation character, like the SimCity series [20]. By organizing resources, a world is to be built in the game. The places where buildings are built can be chosen freely. We also integrated a multiplayer mode. In the beginning of the game, after a storm on the sea, the players are stranded on a deserted island. They find one single item: a ball. However, they can control this ball with their own eyes and get in contact with the island. The initial situation is explained in an intro sequence. A village and resources (trees and quarries) can be built. By creating and collecting the resources, the village expands.

Player 1 wears a mobile eye-tracker [16] and a BCI headset. Due to a high level of usability, we chose the Mindwave Module 2 (Neurosky Inc., USA) headsets, which is also used in 'Focus Pocus'. Eye-tracking aims to increase the accuracy and flexibility of game control.

Player 1 controls a projected ball (Figure 2a), which moves across the playing field towards the point the player is looking at, represented by a red dot. The ball starts rolling when the height of the focus measured by the BCI headset reaches a certain threshold. The height of the focus value and the threshold value are displayed in bars on the sand (Figure 2b). For the prototype, we have defined the threshold based on the premise that it is reachable but not permanently exceeded. The threshold is at 60 on a scale between 0 (no focus) and 100 (focus). When the ball reaches the point the player is looking at, a construction menu is opened (Figure 2c), where resources or the village can be selected by view control. After placement, a circle appears above it, which gradually fills green when the threshold value of the focus is exceeded (Figure 2b). The training duration of the focus is entered by the duration of the filling of the circle. It may be varied according to the child's abilities.

Player 2 complements the abilities of Player 1 by interacting with the sand and generating water. Therefore, the player holds one hand over the sand (Figure 2d). If the focus value is above the threshold, water is generated in this area. The water is needed for the growth of the tree. Based on the Social Cognitive Theory and the tutor model, children can train at different training levels or in cooperation with other children. The village and the resources have different requirements for the terrain to be built. They have to be fulfilled by the players (gods) by changing the sand. Due to the constructive approach, only new objects are built or existing objects are extended. Although it is possible to change the sand at any time, the concept does not include destroying something existing for progress. In detail, this guiding principle can also be found in the BCI control, where the progress achieved stops and does not decrease if the threshold is too low.

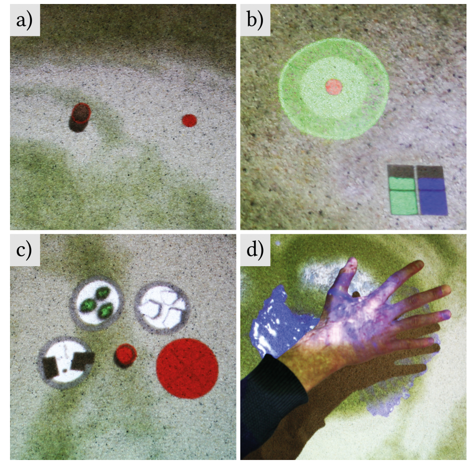

Figure 2: a) Ball (left) and Eye-Tracking Point (right), b) Focus Circle (left), Focus Value and Threshold (right), c) Construction Menu, d) Hand Gesture for Water

3.2 Technical implementation

The AR Sandbox is based on a Linux implementation. The presented system was implemented with the AR Sandbox software [28] as a basis in the programming languages C++, Python and GLSL. For the Mindwave headset, we used an Open Source Linux interface. The headsets are connected to a computer via Bluetooth (Figure 3). The eye-tracking works with the open-source solution from Pupil Labs [16] with a 3D printed frame for pupil and world camera. For the incorporation of the multiplayer into the system a server was programmed in Python, which runs on PC 1 and receives the eye-tracking and focus values of the first Player. Via UDP, data packets the server receives focus values of the second Player on PC 2 and forwards them to the main program.

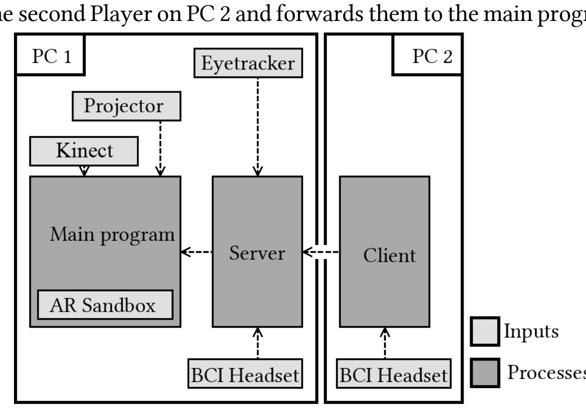

Figure 3: Schema of the technical implementation

4 Evaluation

We conducted an explorative qualitative expert study to evaluate the interplay of the various interaction modalities, as well as the suitability and application possibilities of haptic-supported multiplayer games within the therapy.

4.1 Participants

Seven domain experts (3 female, 4 male) at an age between 21 and 50 years (average age: 36.4) took part in the study. The total duration was approximately 60 minutes per participant. Due to the interdisciplinary questions, we have recruited participants from different disciplines related to the topic (Table 1) by the following criteria: own relation to research in the field of children, technology, medicine, BCI and/or ADHD therapy. Thereby we intended to avoid a bias due to missing background knowledge. All were personally invited and participated separately. The study was recorded by video, audio and a recording clerk. Participants were not encouraged to participate by rewards.

ID	Profession	Sex	Age	Reason for selection
D1	Interaction Designer	f	38	Research: children for medical treatment
D2	Interaction Designer	f	34	Research: people with disabilities (social field / learning)
D3	Interaction Designer	m	28	Research: interaction in medical field
C1	Computer Science	m	21	Technical background
C2	Computer Science	m	42	Research: field of BCI
P1	Neuro-Psychology	m	42	Research: field of ADHS and BCI
P2	Neuro-Psychology	f	50	Therapist for children with ADHD with BCI training

Table 1: Participants of the study (f=female, m=male)

4.2 Procedure

The course of the study was divided into the sections: Information and collection of demographic data (approx. 10 min.), use of the sandbox (approx. 20 min.) and interview (approx. 20 - 30 min.).

4.2.1 Information and demographic data. We informed the participants about the planned use of the sandbox, data protection and documentation. After giving their consent to participate, we recorded demographic data (sex, age, profession).

4.2.2 Collaborative use of the sandbox. The participant (Player 2) tested the sandbox with the study leader (Player 1). Gradually, the study leader explained the individual functions during use and placed resources. The participant adapted the terrain to the required resources and watered the trees, for which the focus of the second Player had to be above the threshold. Resources were built and collected until the village has expanded to level 2. The construction process was the same for all participants, the selection of places and the interaction with sand and water was free. There were no time constraints during use. In addition, we conducted behavioral observations on the interaction between the participant and the study leader during the use of the sandbox.

4.2.3 Interview. We conducted a structured oral interview with open questions. We first asked all participants the same questions about the perception of the game and then questions related to the specific profession and knowledge. Concerning our research questions (Q1-Q4), we asked questions from the categories in Table 2. Afterward we offered an open discussion.

Q1	General, positive and negative aspects of the game, as well as perception of the level of difficulty and own contribution to the success. For designers (D1, D2, D3): Evaluation of the concept of the game, interaction and other ideas.
Q2	Possibility of precise control through BCI headset, eye tracking and sand interaction and subjective perception of combination of these elements. For computer scientists (C1, C2): Conspicuous technical aspects or inconsistencies
Q3	Estimation of complementation of roles of players.
Q4	For psychologists (P1, P2): Suitability of the game for children with ADHD as a supplement to therapy. Suitability and influencing factors on the fun factor of the different roles for children with ADHD, as well as effects of playing together and sand on their motivation. And possibility of use within therapy.

Table 2: Question categories participants were asked

5 Results, Discussion and Future Work

5.1 Results

The results are sorted and summarized according to the above defined research questions Q1-Q4. Conspicuous aspects from the behavioral observations are inserted.

Q1: Overall, the participants rated the prototype as a positive or positive new experience and easy. The joint playing, the interaction with the sand, the integration of a story, the novel technical and conceptual approach and constructive action as the basis of the concept contributed to this. All participants had the feeling to contribute to the overall success of the game. It was mentioned several times that the participants felt powerful/superhuman by interacting by the gesture with the sand and the water. The overall concept, especially the interaction with the sand, was evaluated as positive and intuitive. Even more, tasks could have been aimed at this interaction. The world could be expanded with animations, 3D objects or projections (D3).

Q2: Kinect, eye tracking and BCI headset are not perceived as disturbing, although much technology was used (D2). The use of the system had a calming effect (D1). In observing the behavior, the participants initially interacted with the system a little cautiously. In the early course of the study, the behavior became more natural. They did not appear to have been confused by the technique but were increasingly intrigued by the functions. The precision of the BCI headset control was rated differently. D1 and P1 stated, not to be able to control the BCI input precisely. D3, C1 and P2 described it as moderately accurate. D2 and C2 described it as accurate. D3 described focusing on the hand gesture as helpful. P2 also suspected a postural change as a possible aspect affecting the data. The interaction with the sand was described as precise. It contributes to the game mechanics and gives a pleasant feeling. It is more realistic than on a monitor (P1).

Q3: The distribution of roles was given as the reason that the game was easy for the participants. The role of Player 1 was described by all participants as the guiding role with more responsibility. This was described as a pleasant introduction to the game. Stress arose when the requests from Player 1 could not be fulfilled (D1). The distribution of roles was described as clear (D3), but still mostly complementary. The collaborative play creates the feeling to contribute something to the overall success although, Player 2 was more supportive (D3). Without instructions, it would have been harder for Player 2 (P2). In the long run, D2 suggests an expansion of the skills for the second Player. During use, the players were focused on the task and the atmosphere between them was calm and friendly. This was expressed through calm voices, eye contact, turned postures to each other and smiles. This observation was made for all participants.

Q4: For use in therapy, the prototype needed to be expanded and longer playable. However, the concept itself is much more interesting than a simple monitor application (P1). It is assumed that the haptic has a positive effect. P2 also perceives the training as a possibility for older participants. The role of Player 1 for children with ADHD is not assessed as a suitable start due to its complexity. In contrast, Player 2 is remarkably well suited because it is better to start with a role that is immediately successful. In the long run, the roles can be switched according to abilities. The use of haptics and gestures can support learning (P2). It may also increase the interest in the exercise, which is supposed to lead to a higher learning success (P1). The freedom of creating and intervening in the course of the game will probably please children (P2). For children with ADHD, collaborating is more motivating than competing (P2). This is beneficial due to the low frustration tolerance. The game is therefore also regarded as an excellent training field even if something does not succeed. P2 points out that it is often difficult for children with hyperactivity to sit quietly in front of a monitor. This approach would make it easier to introduce them to training. Children enjoy playing in the therapy (P2). When the diagnosis and therapy plan is completed, it can be used in therapy right from the start. For example, it can be used at the end of the therapy session as a positive conclusion. After the neurofeedback training, this is a transfer situation in which the child receives less feedback. To supplement the therapy, it could still be determined how much training is necessary for a therapeutic effect.

5.2 Discussion

Overall, the evaluation shows technical feasibility and a positive assessment. The subjectively perceived contribution to the overall success is essential, which implies the perception of competence and social cohesion. We have decided to carry out this way of evaluation first to analyze the different aspects of the prototype and in order not to overwhelm or endanger the self-confidence of child participants within the therapy. In addition, it substantiated the suitability for therapy and scenarios for use were created. However, the effect on children should be analyzed next.

The acceptance of the prototype may have been supported by the distribution of roles. This supports the use of a constructive multiplayer model. Due to the possible emotional sensitivity, we assume that children with ADHD may have a higher connection to their game partners. By playing a simulation game without a fixed goal or losing, the flowability may be addressed and frustration kept low. By haptic and movement, the urge for activity can be addressed calmly. The possible stressing effect, if the performance is not achieved, is problematic. Inner stress and the feeling of not being able to cope with the task can result. This shows the relevance to adapting the system to the abilities of the children. This is particularly important for children with ADHD who have different focusing abilities and low frustration thresholds of maintain motivation without reducing self-esteem. Adapted to the learning effect, such stress could be reduced.

It should also be critically examined whether the Mindwave headset is suitable despite low sensors compared to therapy headsets. On the one hand, it has its good usability; on the other hand, therapy headsets may filter more artifacts by e.g., muscle contraction from the EEG signal. It may be evaluated whether HEG (Hemoencephalography) is suitable as an alternative input device due to the movement during training.

The presented concept offers an approach to supplement the current training for children with ADHD. It is not considered a substitute for the current training. The single-player training on the monitor as well as existing games [among others 2, 3, 21] through the setup have their advantages, like a low distraction from outside and possibilities for independent use in-home training with lower technical requirements. As a result of the study, the presented approach could be conducted at the end with the therapist within or as free play after the session.

5.3 Future Work

The study supports the next step to develop the prototype further, as it has been shown that the training in a later version is suitable for use in therapy and can support the children in training. Its effect on the target group and its efficiency should be clinically evaluated with various psychologists and children. The threshold value for the focus should be adaptable to the abilities of the children and ideally contributes to supporting the flow development period. In addition, the onboarding process for the control of BCI controllers may be considered. The task of focusing is a rather abstract instruction learned by try and error. Findings from onboarding processes of free-to-play games can be used because it needs to be especially effective due to high churn rates [22]. The gestures learned may promote the transfer into everyday life, which supports the goal of the therapy, which is to facilitate focusing in everyday life or at school. Building on the system, further player roles can be created to create further social stability by integrating parents, siblings or friends. This may reduce possible stigmatization of the game as a 'training object'. Based on the positive feedback from the adult participants in the presented study, it could be evaluated whether the playful haptic approach is also suitable not only for children but also for adults with ADHD in therapy.

6 Conclusion

In this paper, we present the conception and implementation of a multi-user game prototype, in which components of a BCI training, eye tracking and sand as a haptic component were integrated and which can be used as an expansion for the therapy of children with ADHD in the long-term. Within a qualitative explorative expert study, it was shown that such a system is suitable for use in therapy for children with ADHD and that it can be used from the beginning of the therapy to supplement it.

The use of haptic elements, gestures and interest in training may facilitate it and have a positive effect on the learning process, especially for children with hyperactivity. The integration of a constructive multiplayer mode may promote the motivation of the child with ADHD. Further research should focus on the effect of the system on children and the adaptation to their abilities.

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