Designing VR Games with Gaze Control for Directing Attention of Children with ADHD

1st Linda Graf
Entertainment Computing Group
University of Duisburg-Essen
Duisburg, Germany
linda.graf@uni-due.de

2nd Leslie Scholemann
Entertainment Computing Group
University of Duisburg-Essen
Duisburg, Germany
leslie.scholemann@uni-due.de

3rd Maic Masuch
Entertainment Computing Group
University of Duisburg-Essen
Duisburg, Germany
maic.masuch@uni-due.de

***Abstract*—Within this paper, we want to present a new game concept that combines VR technology and gaze control to direct and train attention in ADHD children. Our approach combines the motivating ability of games with attention-demanding tasks, gaze control, and the high level of immersion of Virtual Reality to design a fun training game for children with ADHD. We describe our design process and give design recommendations for creating games with gaze control and games for children with ADHD.**

***Index Terms*—Gaze Control, Virtual Reality, ADHD, Attention, Game Design**

I. Introduction & Motivation

In the field of medical treatments, digital games offer the advantage that patients a) accept games more likely than conventional treatments and b) in particular games motivate people to hold on [4], [18]. Especially Virtual Reality (VR) games offer the ability to draw the players into the spell of the virtual world, because of its high level of immersion. One successful application of digital games is the use in therapy of Attention Deficit-/Hyperactivity Disorder (ADHD) (e.g. [7], [12], [17]). Children with ADHD suffer from inattention, deficits in executive functions, or altered reward sensitivity, which lead to problems in their everyday lives. Kerns et al. [23] highlighted that systematic training of attention-demanding tasks can increase attentional performances. For example, serious games can help children to learn things about real world situations [11]. An analysis by Craven and Groom [13] of different games that use gaze interaction showed that the oculomotor system is closely linked to attention and that strengthening gaze control also leads to an improvement in attention.

Hence, we combined the ability of VR to captivate the players with the power of gaze control to improve attention and create a game concept to see if the implementation of this combination works. Furthermore, we want to provide a thought-provoking impulse to make more games with this combination to help children with ADHD to train their attention.

As part of the project "MATS" (EFRE-0801423), this work was supported by the European Regional Development Fund (ERDF) 2014-2020.

978-1-6654-3886-5/21/$31.00 ©2021 IEEE

II. Related Work

One of the most diagnosed neurobiological illness in children is the Attention deficit-/hyperactivity disorder [3], [16]. It is characterized in particular by the three main symptoms inattention, impulsivity, and hyperactivity. If the disorder is not treated, it affects the children's school performance and social contacts. Generally, there are several ways to treat ADHD (drug or behavioral therapy, cognitive training [9], or psychoeducation [29]) but one relatively new approach is the use of digital games or serious games. Most of the games are based on standardized diagnostic tools like Stop-Signal, Go/No-Go Task, or the Stroop-Task [12]–[14]. A game developed by [17] includes the training of different executive functions. VR's high level of immersion can be benifical for children with ADHD, as it can completely block out the real world and therefore also block out distracting stimuli. In addition, VR's ability to draw the players into the spell of the virtual world lets the players focus on the challenges to tackle or the task at hand. Another advantage is that VR offers the ability to create realistic environments, in that patients can be tested and treated safely so that the treatment successes can be easily transferred to the real world [28]. Bashiri et al. [6] present a review of different VR applications for the treatment of ADHD. From 20 listed applications, only two were games, while most of them were simulations of classroom situations.

Children with ADHD show deficits in inhibition, action planning, and vigilance [31] as well as focused attention [8]. Munoz et al. [26] hypothesize that impulsivity, hyperactivity, and inattention are due to deficits in inhibitory control. Therefore, they compared participants with ADHD with healthy participants regarding their oculomotor abilities. Oculomotor tasks are well suited to test inhibitory control because the brain regions affected by ADHD and those responsible for saccade control would overlap. They recorded gaze behavior during pro and anti-saccade tasks. Their results showed that participants with ADHD had more problems suppressing unwanted saccades in the anti-saccade task. Thus, there is an altered gaze behavior. They conclude that particular deficits in the endogenous component of attention result from a lack of inhibitory control. Hence, we focus on the training of inhibition control and the endogenous part of attention,

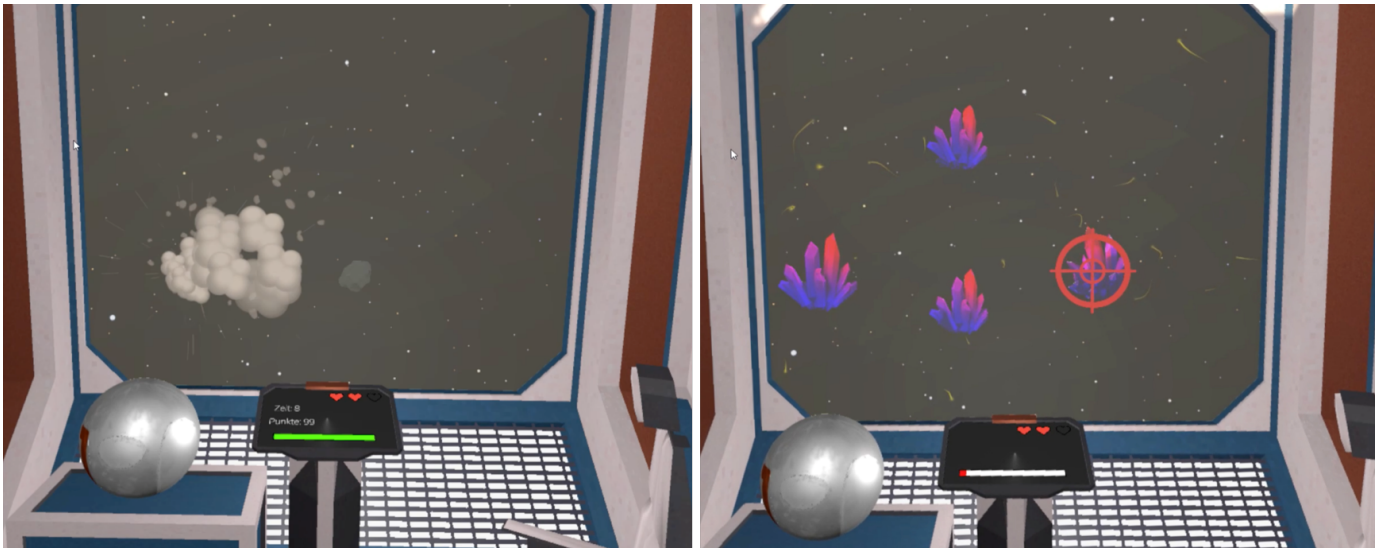

Fig. 1. Left: "*Fast Phase*", Right: "*Focus Phase*"

focused attention, for the design of our application.

Since persons with ADHD show an altered gaze behavior [26], the application of eye-tracking and gaze control has also been used for the diagnostic of ADHD [15] and therapeutic games for ADHD [1]. The latter used a remote-controlled Eye-Tracker system to collect the gaze behavior. However, the approaches of [1] have used conventional output devices such as desktop screens. In our work, we therefore extend these approaches and combine gaze control with VR.

III. Design Recommendations & Game concept

In our literature review and analysis of related applications, we collect design recommendations that guide our design process. In particular, we have included important recommendations for the use of gaze control (G1-5) and aspects that are important when designing for children with ADHD (A1-11).

First, we present five design recommendations that are important when designing games with gaze control. Gaze control describes an input option in which information about eye movement and gaze direction, and pupil size are used. It is particularly interesting because the gaze indicates where the visual attention is currently directed to [25]. Gaze control offers several advantages over other inputs. It is faster and more effortless than other inputs since it does not have to be learned. It also allows for exceptionally smooth operation when combined with other inputs. A significant advantage of games with gaze control is increased immersion during gameplay [30]. A problem when using gaze control is the *Midas Touch Problem* [22]. It describes the use of the eyes as a direct substitute for a mouse, in the sense that any eye movement automatically triggers a computer command. The eyes are constantly in motion and thus permanently look at something. If an action is assigned to each eye movement, the eyes' natural task, seeing, is disturbed. Hence, to create a comfortable gaze control, one should consider the following design recommendations.

G1: Single Player
To focus on the task, it is better if the game is a single-player game instead of a multiplayer game. In a multiplayer game, there are more different interactions between the players, which are difficult to realize all with gaze control [20]. So, single-player mode should be used.

G2: Avoiding *Midas Touch Problem*
To circumvent the *Midas Touch Problem*, the user should be able to decide when he wants to trigger a command and when he wants to look at the scene [22]. One possible solution is to use a second input modality, e.g., a controller. The selection is conducted by gaze control and then confirmed by pressing a button of the controller. So, looking at objects and triggering actions should be separated [19].

G3: Dwell time
The use of dwell time or buttons for the interaction with the game is helpful [1]. In a game, the players usually want to keep an eye on the environment. But if they have to change continuous parameters with the eyes, e.g., to move an object, the ability to observe the environment is limited [21]. Hence, dwell time is another possibility to avoid the *Midas Touch Problem*, as players can directly define when they are looking around and when they want to conduct an action.

G4: Small amount of actions
Due to the problems mentioned before, it is challenging to map different game actions to gaze controls [20]. Additionally, there are fewer other kinds of gaze actions (e.g., dwell time, fixation, saccades) available. Hence, a small amount of actions is recommendable.

G5: Highlighting
When using a controller or a mouse, players often get direct information on where the mouse pointer is pointing at. But where someone is looking at, one is often not even directly

aware of. It is also essential to visualize players' action to provide a feeling of self-efficacy [5], [19]. Hence, information should be highlighted.

Second, we present 12 design recommendations that are important when designing games for children with ADHD. Even if the use of digital games for children with ADHD becomes more and more popular, it is crucial to take the unique needs of those children into account to provide a safe environment. This environment a) does not overstrain them and b) can deal with their tendency to get distracted quickly so that the game also has a chance to bring about what should be brought about. Therefore, one should consider the following design recommendations.

A1: Short Playtime
Children with ADHD do not habe a long concentration span [3]. Also using VR for a longer time can cause cybersickness [27]. Taking both together, the playtime should not be longer than 10 minutes.
A2: Contextualization of the task
Providing a context, a link between experience and learning makes tasks more plausible [10], [14]. Hence, the task should be embedded into a context.
A3: Movement
The use of physical exercise in (exer)games can support the cognitive benefits [27]. Therefore, if it's possible, adding a motor component to the game is recommendable.
A4: Orientation to Standardized Tests
Crepaldi et al. [14] show a significant correlation between game performance and conventional diagnostic tests for ADHD in their game, which were based on these tests. So, standardized tests (e.g., Stop-Signal, Go/No-Go, CPT) seem to be a good guide for the design of training games [13], [14].
A5: Level of difficulty
A gradual increase of difficulty can be helpful not to frustrate the players and to keep them engaged. The game must offer a challenge; otherwise, it can become too dull [1], [10], [12]–[14].Hence, the level of difficulty should be chosen carefully.
A6: Variation & Avoiding repetitions
A variety of different tasks motivate the players to hold on, and it also works against boredom [1], [10], [14]. Complementary to that, repetitions should be avoided to motivate the players to hold on [10]. Hence, a variation of tasks should be used and repetitions should be avoided.
A7: Support & Praise
Another aspect of motivating the players is social support. The players can be supported by motivating encouragements [10], [13], [27] or praise [24] [13]. Children with ADHD have a reduced reward sensitivity. Therefore, short-term rewards should be used.
A8: Feedback
So that children can assess their performance [10], [14], feedback should be direct and multimodal.
A9: Simple Design
The design should be user friendly as well as should avoid overstimulating visual design, and too much distraction [10].
A10: Coloring
Bright colors should be avoided for children with ADHD, as they can also appeal distracting [2].
A11: Sounds & Music
Quiet background noise and music should be used not to distract too much. [2].

Resulting from the design recommendations, we designed a single-player (G1) VR game for the HTC Vive Pro Eye. Players are sent to a space mission, that they have to protect their spaceship from asteroids and take care of enough fuel for the spacecraft to finish the space journey. We used the eye-tracking of the HTC Vive Pro Eye to let the players interact directly with the virtual world. The gaze carried out the main interactions in the game, which means players can select the object that they want to interact with by fixing them with their eyes. All things that the players can interact with are highlighted with visual feedback (G5, A8). To avoid the *Midas Touch Problem* by the object selection (G2), we used the following forms of interactions: Pressing the trigger button of the HTC Vive controller to shoot asteroids and the dwell time (G3) of the gaze to collect the fuel objects. In doing so, we have limited the number of possible actions to these two because it is challenging to implement many control options with gaze control (G4). So that the player knows which form of interaction is currently being used, it is permanently assigned to fixed phases and visualized clear (G5). Children with ADHD show improved performance as well as greater motivation when they are rewarded. Thereby, short-term rewards are preferred (A7). Hence, we choose a robot companion that accompanies the players. The robot gives the players instructions, feedback and praises them.
In total, there should be six phases with slightly increasing difficulty and varying tasks (A5, A6). Thereby, a *Fast Phase* and a *Focus Phase* were designed, which are played alternately. The total playing time should not exceed ten minutes to keep the risk of cybersickness low (A1). Hence, we chose a playtime of approx—8 minutes (1.45 minutes per phase, six playing phases in total). The design of the game is deliberately kept simple (A9). We used muted colors (A10), and background music was omitted (A11). Only shooting asteroids and collecting fuel objects make a sound, which also serves as feedback (A8). We chose a space scenario since the ability to shoot something with the eyes is not questioned in such a scenario (A2).

A. Fast Phase

This phase is an active play mode that serves as an enjoyable onboarding and should increase the players' motivation (A7). Players must direct their gaze at oncoming objects and then use the controller's trigger button to fire a shot at them (G2). The players' task is to destroy as many asteroids as possible within a given time to protect the spaceship. For each asteroid

the players shoot down, they get one point. The players see the asteroids flying directly in front of them through the window towards the spaceship. When the players look at an asteroid, it changes color to indicate that the selection is successful (A8). Once the players have confirmed the selection with the trigger button, the asteroid explodes and is destroyed.

B. Focus Phase

The *focus phase* is where the actual attention exercise takes place. Compared to the *fast phase*, it is quiet and slow. To contextualize this *focus phase*, we choose the process of refueling or recharging the spaceship as an action that requires patience and in which you can concentrate for a moment before the defense starts again in the fast phase (A2). The players must direct their gaze, and thus their attention, to specific objects. If they get distracted and averts their gaze, the progress made is slowly lost again. Children with ADHD have problems suppressing unwanted saccades and consciously controlling fixation. But these deficits can be counteracted through a repeated, targeted control of the gaze [26]. The players' task is to keep their eyes on fuel objects and hold them there until the fuel is completely depleted. At this moment, we address the focused attention. If they get distracted by other objects and averts their gaze, the progress will be lost. If the players' gaze is on the fuel object, it will slowly grow smaller, and if it loses focus, it will grow back to its original size. During this phase, the players' gaze is visualized by a red crosshair (A8). Through this visualization, the players' gaze is clarified and made aware. To increase the level of difficulty (A5), we added more distractions in each of the three *Focus Phases* (e.g., astronauts or stars flying through space while the players have to fix the fuel objects with their gaze). By adding the distractions during the attention task, we also address the inhibitory control.

IV. Discussion and Future Research

We created a VR game for children with ADHD that combines gaze interaction to focus attention and a playful virtual environment that should maintain the players' motivation. Guided by theory, we have established design recommendations that will serve as a basis for designing games for children with ADHD and games with gaze control. There is both research on VR games for ADHD children and games for children with ADHD that use gaze control, but - to our knowledge - no game designs yet combine both. Our game prototype shows that the design recommendations can be implemented well. We created the *focus phase* that includes the actual attention task. The players' gaze has to be used purposefully by keeping the eye and the attention on an object for a longer time. For the motivation and to maintain fun during the game, we also created the *fast phase*, which reminds us of a simple shooter game, which is usually rated as fun [10], [13]. In the next step, we plan to conduct an evaluation in which we will subject children with ADHD to a training phase and compare attention performance before and after that. Before that, we want a few ADHD children to test the game first to see how they get along with the gaze control and if we need to make any adjustments to the game design before we can evaluate its impact on attention.

We present a new game concept to help children with ADHD train their attention. For this, we combine the high immersion of VR technology and especially the gaze control as an operation. The combination of these three elements seems to be a promising method for use in ADHD therapy. We also collect design recommendations from the literature that might help designing future applications.

References

[1] Ashwag Al-Shathri, Areej Al-Wabil, and Yousef Al-Ohali. Eye-controlled games for behavioral therapy of attention deficit disorders. In *International Conference on Human-Computer Interaction*, pages 574–578. Springer, 2013.

[2] Alaa Eddin Alchalcabi, Amer Nour Eddin, and Shervin Shirmohammadi. More attention, less deficit: Wearable eeg-based serious game for focus improvement. In *2017 IEEE 5th international conference on serious games and applications for health (SeGAH)*, pages 1–8. IEEE, 2017.

[3] AP American Psychiatric Association, American Psychiatric Association, et al. Diagnostic and statistical manual of mental disorders: Dsm-5, 2013.

[4] Sylvester Arnab. *Serious games for healthcare: Applications and implications: applications and implications*. IGI Global, 2012.

[5] Othman Asiry, Haifeng Shen, and Paul Calder. Extending attention span of adhd children through an eye tracker directed adaptive user interface. In *Proceedings of the ASWEC 2015 24th Australasian Software Engineering Conference*, pages 149–152, 2015.

[6] Azadeh Bashiri, Marjan Ghazisaeedi, and Leila Shahmoradi. The opportunities of virtual reality in the rehabilitation of children with attention deficit hyperactivity disorder: a literature review. *Korean journal of pediatrics*, 60(11):337, 2017.

[7] Aida Bikic, James F Leckman, Torben Ø Christensen, Niels Bilenberg, and Søren Dalsgaard. Attention and executive functions computer training for attention-deficit/hyperactivity disorder (adhd): results from a randomized, controlled trial. *European child & adolescent psychiatry*, 27(12):1563–1574, 2018.

[8] Hanoch Cassuto, Anat Ben-Simon, and Itai Berger. Using environmental distractors in the diagnosis of adhd. *Frontiers in human neuroscience*, 7:805, 2013.

[9] Ferrán Catalá-López, Brian Hutton, Amparo Núñez-Beltrán, Matthew J Page, Manuel Ridao, Diego Macías Saint-Gerons, Miguel A Catalá, Rafael Tabarés-Seisdedos, and David Moher. The pharmacological and non-pharmacological treatment of attention deficit hyperactivity disorder in children and adolescents: a systematic review with network meta-analyses of randomised trials. *PloS one*, 12(7):e0180355, 2017.

[10] Chiara Eva Catalano, Angelo Marco Luccini, and Michela Mortara. Best practices for an effective design and evaluation of serious games. 2014.

[11] Alan Chalmers and Kurt Debattista. Level of realism for serious games. In *2009 Conference in Games and Virtual Worlds for Serious Applications*, pages 225–232. IEEE, 2009.

[12] Vera Colombo, Davide Baldassini, Stefano Mottura, Marco Sacco, Maura Crepaldi, and Alessandro Antonietti. Antonyms: A serious game for enhancing inhibition mechanisms in children with attention deficit/hyperactivity disorder (adhd). In *2017 International Conference on Virtual Rehabilitation (ICVR)*, pages 1–2. IEEE, 2017.

[13] Michael P Craven and Madeleine J Groom. Computer games for user engagement in attention deficit hyperactivity disorder (adhd) monitoring and therapy. In *2015 International Conference on Interactive Technologies and Games*, pages 34–40. IEEE, 2015.

[14] Maura Crepaldi, Vera Colombo, Stefano Mottura, Davide Baldassini, Marco Sacco, Alessandro Antonietti, et al. Antonyms: a computer game to improve inhibitory control of impulsivity in children with attention deficit/hyperactivity disorder (adhd). *Information*, 11(4):230, 2020.

[15] Senuri De Silva, Sanuwani Dayarathna, Gangani Ariyarathne, Dulani Meedeniya, Sampath Jayarathna, Anne MP Michalek, and Gavindya Jayawardena. A rule-based system for adhd identification using eye

movement data. In *2019 Moratuwa Engineering Research Conference (MERCon)*, pages 538–543. IEEE, 2019.

[16] Manfred Döpfner, Dieter Breuer, Nora Wille, Michael Erhart, and Ulrike Ravens-Sieberer. How often do children meet icd-10/dsm-iv criteria of attention deficit-/hyperactivity disorder and hyperkinetic disorder? parent-based prevalence rates in a national sample–results of the bella study. *European child & adolescent psychiatry*, 17(1):59–70, 2008.

[17] Sebastiaan Dovis, Saskia Van der Oord, Reinout W Wiers, and Pier JM Prins. Improving executive functioning in children with adhd: Training multiple executive functions within the context of a computer game. a randomized double-blind placebo controlled trial. *PloS one*, 10(4):e0121651, 2015.

[18] H Lynn Horne-Moyer, Brian H Moyer, Drew C Messer, and Elizabeth S Messer. The use of electronic games in therapy: a review with clinical implications. *Current psychiatry reports*, 16(12):520, 2014.

[19] Felix Hülsmann, Timo Dankert, and Thies Pfeiffer. Comparing gaze-based and manual interaction in a fast-paced gaming task in virtual reality. In *Proceedings of the Workshop Virtuelle & Erweiterte Realität 2011*, 2011.

[20] Poika Isokoski, Markus Joos, Oleg Spakov, and Benoît Martin. Gaze controlled games. *Universal Access in the Information Society*, 8(4):323–337, 2009.

[21] Rob Jacob and Sophie Stellmach. What you look at is what you get: gaze-based user interfaces. *interactions*, 23(5):62–65, 2016.

[22] Robert JK Jacob. What you look at is what you get: eye movement-based interaction techniques. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 11–18, 1990.

[23] Kimberly A Kerns, Karen Eso, and Jennifer Thomson. Investigation of a direct intervention for improving attention in young children with adhd. *Developmental neuropsychology*, 16(2):273–295, 1999.

[24] Marjolein Luman, Jaap Oosterlaan, and Joseph A Sergeant. The impact of reinforcement contingencies on ad/hd: a review and theoretical appraisal. *Clinical psychology review*, 25(2):183–213, 2005.

[25] Päivi Majaranta and Andreas Bulling. Eye tracking and eye-based human–computer interaction. In *Advances in physiological computing*, pages 39–65. Springer, 2014.

[26] Douglas P Munoz, Irene T Armstrong, Karen A Hampton, and Kimberly D Moore. Altered control of visual fixation and saccadic eye movements in attention-deficit hyperactivity disorder. *Journal of neurophysiology*, 90(1):503–514, 2003.

[27] Yang-Kun Ou, Yu-Lin Wang, Hua-Cheng Chang, Shih-Yin Yen, Yu-Hua Zheng, and Bih-O Lee. Development of virtual reality rehabilitation games for children with attention-deficit hyperactivity disorder. *Journal of Ambient Intelligence and Humanized Computing*, 11(11):5713–5720, 2020.

[28] Albert "Skip" Rizzo and Gerard Jounghyun Kim. A swot analysis of the field of virtual reality rehabilitation and therapy. *Presence: Teleoperators & Virtual Environments*, 14(2):119–146, 2005.

[29] Peter F Schlottke, Ute Strehl, and Gerhard W Lauth. Aufmerksamkeitsstörung. In *Lehrbuch der Verhaltenstherapie*, pages 411–428. Springer, 2009.

[30] J David Smith and TC Nicholas Graham. Use of eye movements for video game control. In *Proceedings of the 2006 ACM SIGCHI international conference on Advances in computer entertainment technology*, pages 20–es, 2006.

[31] Erik G Willcutt, Alysa E Doyle, Joel T Nigg, Stephen V Faraone, and Bruce F Pennington. Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biological psychiatry*, 57(11):1336–1346, 2005.