

*Original research article*

## **Mind Marvel: Transforming Attention Deficit Disorder with Hyperactivity Challenges into Opportunities through Interactive Gaming**

**Noyal Babu<sup>1</sup>, Neil Buckley<sup>1</sup>, Emanuele Lindo Secco<sup>2,\*</sup>**

<sup>1</sup> AI Lab, School of Mathematics, Computer Science and Engineering, Liverpool Hope University

<sup>2</sup> Robotics Lab, School of Mathematics, Computer Science and Engineering, Liverpool Hope University

\* Corresponding author: [seccoe@hope.ac.uk](mailto:seccoe@hope.ac.uk)

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### **Abstract**

*Attention Deficit Disorder with Hyperactivity* (ADHD) is a neurological disorder associated with pattern of inattention and hyperactivity-impulsivity. Signs and symptoms of ADHD can be observed in the early stage of childhood and therefore a prompt diagnosis associated with a proper treatment is critical. Once diagnosed, different treatments are available such as behavioral therapy, medication and cognitive training; recent studies have shown that ADHD people are well responding to interactive games and technologies such as *Virtual Reality* (VR) because these games require timely task completion, attention to detail and concentration. The aim of this work is to leverage on game therapy for ADHD and design Mind Marvel, a novel platform for ADHD. The Mind Marvel platform combines the design of interactive web pages with a VR environment transforming Attention Deficit Disorder with Hyperactivity Challenges into opportunities through such interactive gaming. The end user is involved in answering to set of questions and performing a VR game with a computer mouse, the keyboard, or a commercial VR controller. The platform has been tested in laboratory conditions: preliminary results show the capabilities of the Mind Marvel system to support and challenge ADHD.

**Keywords:** Attention Deficit Disorder with Hyperactivity; Attention Deficit Disorder; ADHD; Treatment; Therapy; Virtual Reality

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## 1. Introduction

*Attention Deficit Hyperactivity Disorder* (ADHD) is a neurodevelopment disorder often classified by a persistent pattern of inattention and hyperactivity-impulsivity found in both children and adults<sup>[1]</sup>. The after-effects of ADHD vary from person to person. Some find it difficult to do their daily activities, while others can cope with it. Patients with ADHD disorder tend to have deficits in higher-level cognitive functions needed for mature, goal-directed behavior and appropriate growth<sup>[2]</sup>. Moreover, signs and symptoms like fidgety, impulsiveness, talkative, and interrupting behavior of ADHD can be observed in the victim's childhood. Primary care providers can guide and assist them in supporting their lives promptly. Evaluation and diagnosis done by medical teams, such as psychiatrists or clinicians, can further aid in improving.

### 1.1. ADHD

ADHD is not a newly evolved disorder. The history begins with the clinical reports about the unruliness behavior of children from parts of Europe around two centuries ago. Research and outcomes regarding ADHD are obtained from two different angles: biomedical and historical-behavioral psychology<sup>[3]</sup>. In the scope of biomedical concepts, ADHD is a neurobehavioral condition found in an individual since childhood. As stated by the *National Health Service* (NHS), people with ADHD exhibit characteristics such as restlessness, diminished focus, deficient concentration skills, and a propensity to act impulsively. It is not a spreadable disease but rather a group of hyperactive symptoms causing changes in the victim's behavior, emotional intelligence, psychological, and learning capabilities<sup>[4]</sup>.

Signs and symptoms of ADHD can be observed in the early stage of childhood and become more evident by the changing environment (like when the child starts schooling). This attention deficit disorder in a child can overlap with normal behavior development. Diagnostic manuals like DSM-5, ICD-11 and RDoC prefer diagnosis of ADHD in individuals under the age of '12' if they display multiple inattentive and hyperactive-impulsive signs<sup>[5]</sup>. Studies conducted by 'The World Federation of ADHD International Consensus Statement: 208 Evidence-Based conclusions about the disorder state that around 5.9% of youth and 2.5% of adults are diagnosed with ADHD symptoms<sup>[6]</sup>. When we take gender into account, the male-female sex ratio of having ADHD is balanced among them. In children, about 2.5 and 4 times more males than females present with ADHD<sup>[7]</sup>.

## 1.2. Treatment Methods

Once the individual is diagnosed with ADHD, the next procedure is to follow a treatment regime. They are mapping the diverse array of treatment modalities utilized for ADHD treatment (**Table 1**). A comprehensive grasp of various approaches provides insight into how treatments can assist in the recovery or management of individuals with ADHD. In the context of these different approaches, it is also worth to mention that games could be designed and used as a treatment platform in order to interact with the brain of the end-user.

**Table 1.** ADHD treatment methods.

Treatment Method	Approach
Behavioural Therapy	<ul style="list-style-type: none"> <li>• It is a therapeutic approach to reduce the ADHD symptoms.</li> <li>• It is the initial treatment received when the diagnosis is positive for ADHD<sup>[8]</sup>.</li> </ul>
Medication	<ul style="list-style-type: none"> <li>• Medications do help to manage the ADHD symptoms but do not rectify them.</li> <li>• The medications act differently in different people.</li> <li>• Proven to have side effects like sleep deprivation and reduced appetite<sup>[8]</sup>.</li> </ul>
Cognitive Training <sup>[9,10]</sup>	<ul style="list-style-type: none"> <li>• Helping the victim to control the ADHD symptoms by altering their thoughts and behaviour.</li> <li>• Cognitive training is achieved via talking therapy, training exercises or cognitive improvement games.</li> </ul>
Food Diet <sup>[9]</sup>	<ul style="list-style-type: none"> <li>• Include a healthy and balanced diet.</li> </ul>

Various brain games, puzzles, teasers, and quizzes might contribute, in fact, to developing specific aspects of brain function, like memory, problem-solving, and thinking skills. Video games may also aid a child in leveraging feelings and emotions like sadness, anger, and competitiveness among other players. In this context, since the era of COVID-19, there has been a significant surge in online game players: according to a study conducted by Statista on ‘Global Video Game Users

2027’ concludes that the number of video gamers in 2023 is 2.64 billion. This number keeps increasing till 2027<sup>[11]</sup>.

Focusing on a possible treatment for ADHD, video games may then represent a useful tool. Studies show that people respond well to the game instructions and follow them in the timed frame. Games encourage values like timely task completion, attention to detail, concentration skills, persistence, the need to learn, and motivation to succeed<sup>[8-11]</sup>. Considering all these factors, video games remediate patients' attitudinal, behavioral, and emotional processes with impulse-related disorders<sup>[12]</sup>. With the vast technological growth, doctors and health professionals seek more sophisticated and cost-effective treatment methods. Some of the current games that are well-designed to cure, treat and control specific health conditions are listed in **Table 2**.

**Table 2.** Video Games that aid in improving certain health conditions.

Health Condition/ Disorder	Video Games	Approach
Cancer	Re-Mission	The Game helps patients stay positive, educates them about the treatment and motivates them to fight cancer <i>Game link</i> <a href="https://hopelab.org/case-study/re-mission/">https://hopelab.org/case-study/re-mission/</a>
Asthma	Asthma Sense	This game teaches the asthma patient about using inhalers, asthma conditions, and treatment procedures <i>Game link</i> <a href="https://www.mobihealthnews.com/tag/asthmasense-app">https://www.mobihealthnews.com/tag/asthmasense-app</a>
HIV	Play Forward: Elm City Stories	Here, the players are advised to be cautious about HIV, avoid all risky behaviours and be educated about the aftereffects of HIV <i>Game link</i> <a href="https://schellgames.com/portfolio/playforward-elm-city-stories">https://schellgames.com/portfolio/playforward-elm-city-stories</a>
Obesity	Escape from Diab	Provides education for children on healthy food habits and proper way of eating. The game addresses the situation of obesity <i>Game link</i>

		<a href="https://artsandculture.google.com/asset/escape-from-diab/7wHm5mz7rff4IA?hl=en">https://artsandculture.google.com/asset/escape-from-diab/7wHm5mz7rff4IA?hl=en</a>
Anxiety or Depression	Mind Light	Games for people to overcome anxiety and depression. They are scientifically proven technology and provide a safe environment <i>Game link</i> <a href="https://www.theplayniceinstitute.com/">https://www.theplayniceinstitute.com/</a>
Stroke	Rehabilitation Gaming System (RGS)	This game uses highly innovative Virtual Reality and novel technology to enhance the cognitive functions of stroke survivors <i>Game link</i> <a href="https://www.aal-europe.eu/projects/rgs/">https://www.aal-europe.eu/projects/rgs/</a>
Diabetes	Packy & Marlon	The game provides an educational platform for children to know about diabetes mellitus type 1. It improves the self-care behaviour in the patients <i>Game link</i> <a href="https://en.wikipedia.org/wiki/Packy_and_Marlon">https://en.wikipedia.org/wiki/Packy_and_Marlon</a>

### 1.3. Design and Purpose of ADHD Games

The aim of this work is to leverage on gamification of therapy and suggest an approach towards ADHD based on Video Games for Therapeutic Intervention. The idea of this work was inspired by the analysis presented by Craven MP and Groom MJ – in Computer Games for User Engagement in ADHD Monitoring and Therapy) - which focused on three main approaches we have taken into account while developing this work<sup>[13]</sup>.

A *task-focused game* enhances human performance, attention, and perception tests by challenging the player with a dynamic environment, and testing speed and agility in completing the task. Moreover - according to an investigation carried out by Oei and Patterson on the executive functions of the gamers - playing action, puzzles, or memory games tend to have improvised cognitive function<sup>[13]</sup>. Secondly, in terms of *Educational Achievement*, using games as a therapeutic method could improve the ADHD condition, since games can be designed to train specific brain aspects like theta/beta ratio and SCP amplitude using time-to-time feedback<sup>[13]</sup>. This approach, which is also known as *neuro-feedback*, enables the transfer of the player's cognitive

function to a better state, thereby reducing the ADHD condition. Under the umbrella of the neuro-feedback are games which include gaze control to track the eye movement and system like the CogMed, which targets working memory through challenging tasks<sup>[13]</sup>. The third focus is the *Improvement of the Medical Condition* and therefore to build a game that helps the therapist or clinician analyze this neuro disorder's health condition. As mentioned in Table 2, many digital online games help detect and assess symptoms of various health conditions. A digital game designed for ADHD identifies the symptoms if present in the player.

#### **1.4. Cognitive Improvements and Limitations**

Among video games, a special mention should be devoted to Virtual Reality (VR) applications. VR games enhance the user's senses by providing a simulated environment replicating real-world experiences. These environments can trigger cognitive processes such as memory, problem-solving, and concentration skills.

The flexibility in creating diverse environments within VR makes it an optimal method for exposing patients to triggering environments. VR can improve cognitive functions through enhanced engagement, multiple sensory stimulation, training tasks, and rapid response in a simulated environment. Active participation and honest reactions are obtained since the user interacts with surroundings like the real world. Studies indicate that VR is a systematic and controllable approach that uses data visualization and immediate feedback to analyze the player's performance<sup>[14]</sup>. It replaces the traditional method of cognitive treatment using paper and pencil. The article 'Effects of incorporating virtual reality training' by Chiu, Hsu, and Ouyang 2023, discusses the VR training that interacts with motor and cognitive skills, tends to reduce stress, depression, anxiety, and fatigue, and improves overall relaxation, calmness, coping skills<sup>[15]</sup>. VR interactions offer immersive simulations that induce emotions and alleviate potential psychological conditions. The VR games, such as EndeavorRx, as discussed in Table 3, can potentially train individuals with certain neuro-disorders to comprehend their condition, foster the development of cognitive skills, and progressively mitigate the symptoms of ADHD.

With the positive aspects of training cognitive skills and improving the ADHD condition in the victims, digital games may also negatively impact the player. Research conducted by The ADHD Centre, a leading UK ADHD Assessment clinic, indicates that ADHD people tend to have more impulsive and curious behaviour, leading to addiction towards video games<sup>[16]</sup>. Especially

among children, increased impulsivity can decrease the ability to self-control. Excessive gaming can lead to hyperfocus, avoiding necessary information among them. Moreover, games are sometimes utilized to escape uncomfortable real-world situations, potentially impeding personal growth and social skills development. Therefore, it is recommended that individuals with ADHD utilize digital mediums as a treatment method under the guidance and supervision of a clinician.

## 1.5. Aims and Objectives

According to the above considerations, this work aims at developing an ADHD platform named *Mind Marvel Platform* to aid and support ADHD people. The objectives of the proposed design are:

1. To leverage on gamification in order to support diagnosis and cognitive skills in ADHD.
2. To encapsulate current findings on ADHD vs our design.
3. To test and compare different applications and then optimize and build the *Mind Marvel Platform*.

The overarching goal of this approach is to build a public platform which can also raise awareness about ADHD with no claim, at this stage, of clinical validation.

The aim is to develop an easily accessible, enjoyable, informative, and supportive app replicating a fully functional application. The user should be able to understand more about ADHD and be equipped to recognize its symptoms within themselves. The following text is organized as follows: **Section 2** focuses on the material and methods presenting the technologies and the proposed design of the platform together with the testing of the system. **Section 3** presents the results and it is followed by a Discussion (**Section 4**) and Conclusion (**Section 5**).

## 2. Materials and methods

This section delineates the methodologies and technologies employed in creating the ‘Mind Marvel’ webpage. The webpage is conceived as a dedicated platform for propagating awareness about ADHD. The game incorporated into the platform aims to identify the potential symptoms of ADHD if present in the player. The technological tools utilized in this work’s development

encompass React, JavaScript, and VR/XR. The primary objective is to offer a valuable platform for those grappling with ADHD. The selected technologies and game components are strategically chosen to align with the research findings and contribute to facilitating ADHD-related challenges. Through this methodological approach, the Mind Marvel webpage aspires to impact the well-being of people living with ADHD.

## 2.1. Tools and Technologies

The *Mind Marvel Platform* is a dynamic web application created on the React platform incorporating a VR (Virtual Reality) experience. The entire platform is coded in JavaScript. The a-Frame library is used on top of HTML to build an immersive environment for the ADHD game. Detailed studies on the technologies and tools used in the Mind Marvel design are mentioned below. In order to design the proposed system, the following elements and definitions are needed

*Web Application* – An application program that is coded in a remote server and then delivered to a browser via the internet is called a web application<sup>[17]</sup>.

*Virtual Reality* – Digital technologies are used to build an immersive environment for a better user experience<sup>[18]</sup>. VR is opted for the Mind Marvel system due to its ability to immerse users in a simulated environment. The user can control the virtual surroundings using the keyboard, mouse, or other devices. On the Mind Marvel website, users are introduced to a semi-immersive VR game designed to fully engage their senses and integrate them into the gaming environment. Therefore the platform can stimulate the visual and auditory senses and provide a comprehensive user experience.

*React* – *React.js*, an open-source JavaScript library developed by J Walke (Facebook/META®), is the foundational framework for constructing the Mind Marvel webpage. Traditional JavaScript applications require manual DOM manipulation to reflect data changes, leading to full-page reloads. React introduces *Single-Page Applications* (SPAs), optimizing performance by selectively updating portions of the webpage without complete reloads, resulting in a more dynamic user experience<sup>[19]</sup>.



*Node* – *Node.js* is a JavaScript library mainly used to run JavaScript on the server<sup>[20]</sup>. It is used to develop a dynamic website that offers great user experience. Node.js is downloaded to the machine, and npm is used to install further packages. React and Node.js are combined in the platform, aiming to build a dynamic, data-driven, extensive web application across multiple platforms.

*A-Frame* – *A-Frame* is a web framework for developing a virtual reality environment using HTML<sup>[21]</sup>. The most used and widely accepted method to build VR content. A-Frame, built on HTML, offers a straightforward implementation for users. Its core lies in a robust entity-component framework. A-Frame is also compatible with various VR commercial headsets.

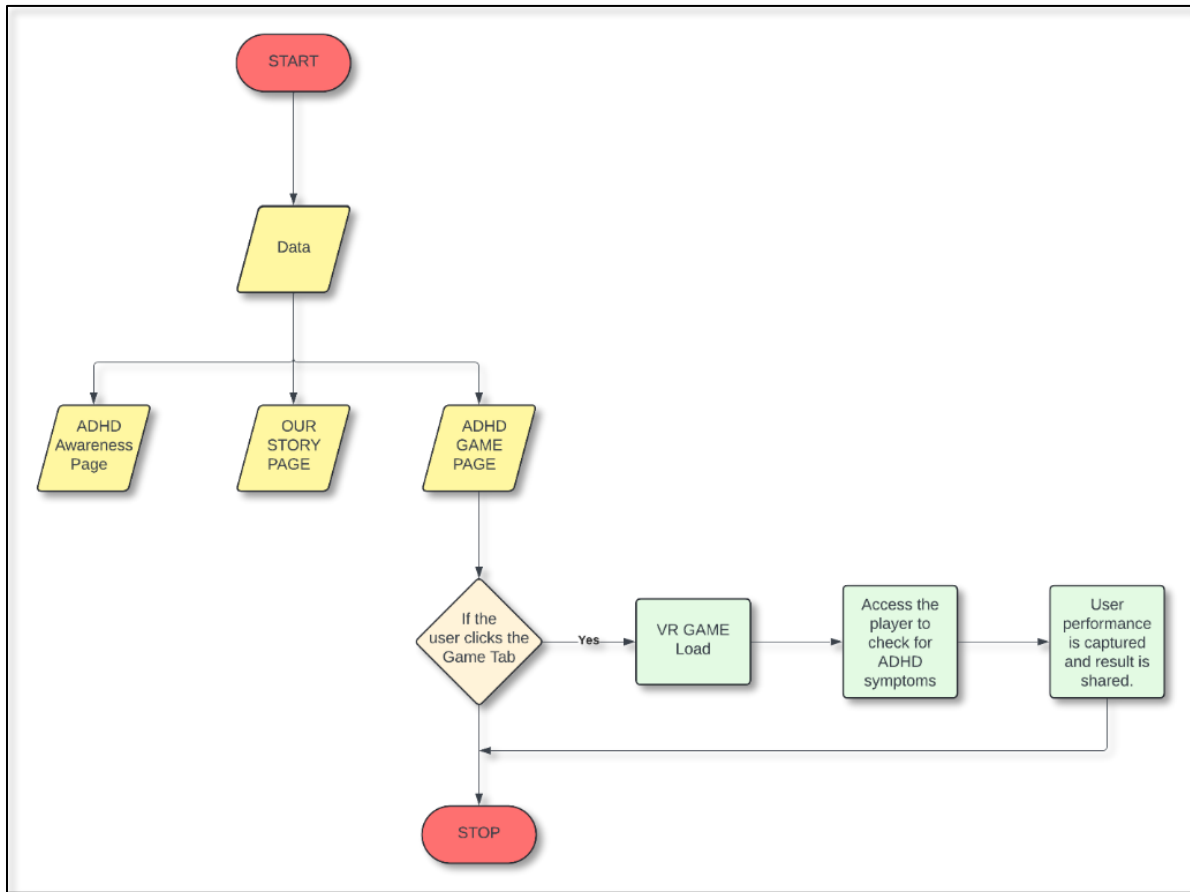
*Three* – *Three.js* is a JavaScript 3D library for creating and displaying 3D models in applications. In our Mind Marvel system, Three.js library is used to assist A-Frame with (i) loading 3D models to the scene with the help of ‘GLTFLoader’ and (ii) keeping track of child elements in the scene. Moreover the A-Frame is built on top of Three.js.

*Sketchfab* - This is an online platform that provides 2D and 3D models for free downloads. Incorporating a VR environment alongside 3D models enhances user experience by closely mimicking real-world scenes. For this work, the 3D models used in our platform are the *Monkey Model*, the *White and Yellow Duck* and the *Lake Model* which are available at the fooling links, respectively:

1. Monkey model: <https://skfb.ly/VYJ9>
2. White duck: <https://skfb.ly/oBRTA>
3. Yellow duck: <https://skfb.ly/6ZpIF>
4. Lake model: <https://skfb.ly/MYJw>

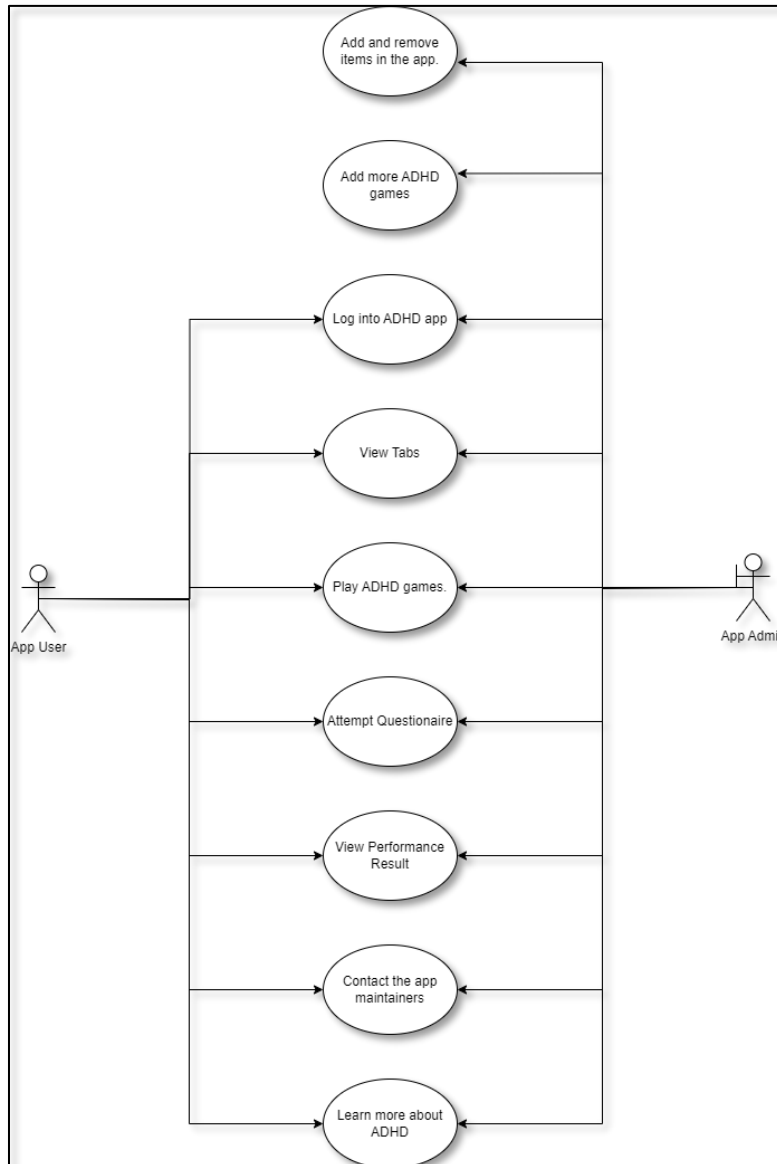
## 2.2. Rational and Concept

In the first stage, the Mind Marvel platform’s working blueprint has been designed in a Flowchart Diagram. The main features and functionalities were outlined in a use-case diagram as it is shown in **Figure 1**.



**Figure 1.** Flowchart of the Mind Marvel Platform

The figure displays a graphical representation of the platform. The primary task was to outline the representation and algorithm of the application. Once the working of the application was outlined, the next step involved identifying the users and the use cases it offers.



**Figure 2.** Use-case diagram of the Mind Marvel Platform

Then a more in-depth set of details has been defined: **Figure 2** depicts the users and their interactions with the app. The concept is that when the user enters the Mind Marvel Platform or Application, a home page appears with three tabs. A tab for the ADHD awareness page, another for reasoning about the project's purpose, and a final tab for the ADHD game. The intention is to create a game aimed at helping players recognize potential indicators of ADHD within themselves while also providing feedback on their performance outcomes.

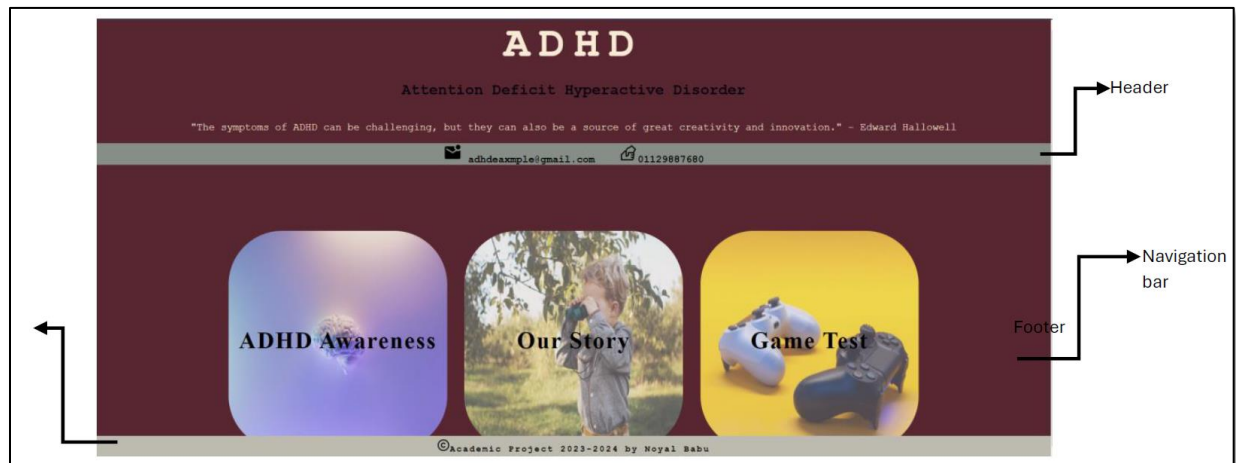
At this stage, in order to understand our approach, it is important to notice what it follows: the idea of developing an immersive visual game for the ADHD project also originated from an experiment conducted by National Geographic to explore brain function. National Geographic TV is a team that researches and explains the science behind the facts<sup>[22]</sup>. In the experiment, the audience counted the jumps made by girls wearing green tops in a double Dutch game. Despite the straightforward task, participants were bombarded with distractions: backgrounds changing, additional players entering the scene, new characters introduced, and more. In this case, the objective was to assess whether the brain could maintain focus amidst these dynamic changes and complete the task. The experiment's outcome indicated that most of the audience struggled to keep track of all the alterations occurring in the video. In other words, when overloaded with stimuli, the brain prioritizes one aspect, diminishing attention to the rest<sup>[23]</sup>. This experiment provided the groundwork for the development of an ADHD-focused game.

### 2.3. Design

This Section documents the operations and mechanisms of the Mind Marvel website. Once the *npm* command initiates the client-side operations in React, the website becomes accessible via browsers. The website's color scheme is deliberately selected to enhance both the aesthetic appeal and the overall standard of the webpage. The choice of font and colors facilitates ease of reading for the audience. Most of the text on the page is in the font type *Courier New*, *Courier*, *monospace*. The background color used is *hsl (348, 40%, 25%)*.

### 2.4. The Mind Marvel Website

The Mind Marve webpage is organized as it is shown in **Figure 3**.



**Figure 3.** The Home page of the Mind Marvel Platform

**Figure 3** depicts the *Home Page* users initially encounter on the Mind Marvel site. The page has three sections: the *Header*, the *Navigation Bar*, and the *Footer*. The Header includes contact details such as email and phone number. The Navigation Bar features three tabs, each facilitating users to explore more about ADHD. Finally, the Footer provides information about the developers.

An ADHD Awareness Page (**Figure 4**) aims to advocate for ADHD. Despite its acronym standing for Attention Deficit Hyperactive Disorder, there remains a lack of widespread recognition of ADHD as a legitimate disorder among the public. Many countries like the USA have passed the ‘Disabilities Act’ that includes people living with ADHD to protect them<sup>[24]</sup>. However, awareness is a pressing need to ensure the utilization of these legal protections. There is a prevailing tendency for society to expect individuals affected by ADHD to exert more significant effort to mitigate their symptoms, including fidgeting, hyperactivity, and reduced attention span. This attitude might hinder the victims from getting treatment, attention, and care in the early stages. As mentioned earlier, there exist a group of people living with ADHD unaware of their condition. This website endeavors to foster understanding and awareness of ADHD in society.



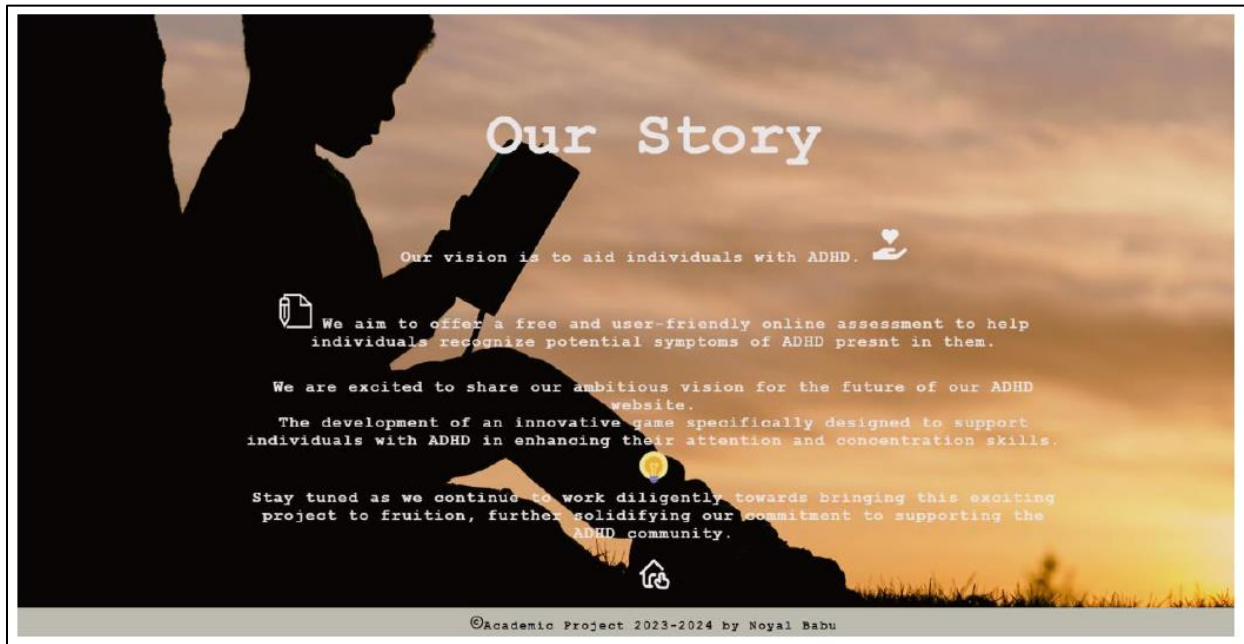
**Figure 4.** The Awareness Page with three significant concerns regarding ADHD addressed on the page

On clicking the ADHD Awareness tab, three generic concerns regarding ADHD are displayed on the page, each in a box. The three questions are: (i) *What is ADHD?*, (ii) *Signs and Symptoms*, and (iii) *Common Facts about ADHD*. The webpage is structured to encourage user interaction with its components, aiming to create an engaging and enjoyable experience within the awareness section. Upon hovering over the box, the answer to the question is displayed. To enhance the design of the page, a dynamic background is added. Five random images of animals appear every 5 s. At the end of the session, the user is presented with a question to raise awareness of their attention and concentration levels. Use the home icon at the bottom to navigate to the home page.

The reason for developing an ADHD awareness platform is explained to the user on the Our Story page. The project's vision is to provide a supportive platform tailored to aid individuals affected by ADHD. Furthermore, it outlines the forthcoming updates, detailing the features and functionalities to enhance the user experience. The story behind the creation humanizes the effort and dedication invested, fostering a deeper connection with the audience. Ultimately, it connects potential customers to the application.

The ADHD people often find it challenging to maintain sustained attention. To address this, the webpage integrates minimal messaging and relevant icons. This approach communicates our message to all users succinctly and expediently, acknowledging the audience's diverse needs. A

home icon prominently displayed at the bottom of the page offers seamless navigation back to the homepage.



**Figure 5.** The Our Story page, that is the main purpose of undertaking this work

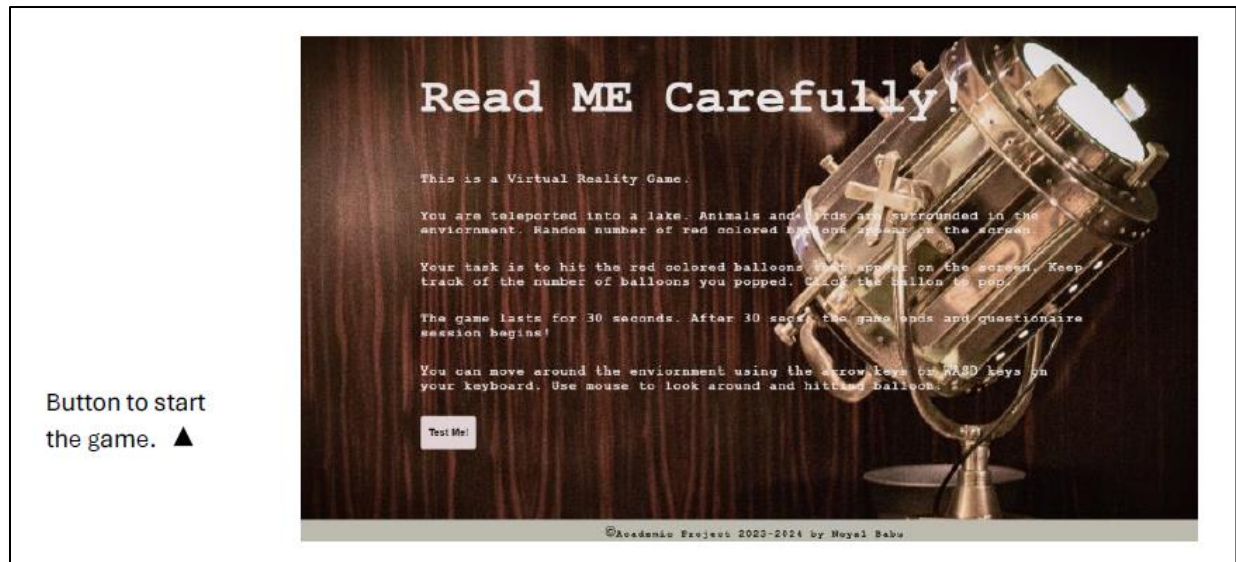
## 2.5. Gaming and Testing

On clicking the 'Game Test' tab, the user is directed to the ADHD assessment game, which is the prime focus of this work. An immersive VR game is developed to assess the users. The performance exhibited by the user is analyzed using their cognitive skill.

### Gaming

Figure 6 refers to the instruction page outlining the task and procedures to play. Users are teleported into the VR environment. Sounds, images, and models are added to enhance the VR experience. The user is given a single task to complete in 30 s. Click the *Test Me!* button to initiate the game. A lake forest simulation is designed in the platform. The 3D models from Sketchfab are used to set the lake ambience. Three animals are depicted in the game. Each animal appears randomly in the game to distract the user. Sounds are added to the background to enhance the immersive experience. In the environment, random static balloons are displayed. The balloons are blue and have a significant role in the game. At the game's onset, the user is allocated a time limit

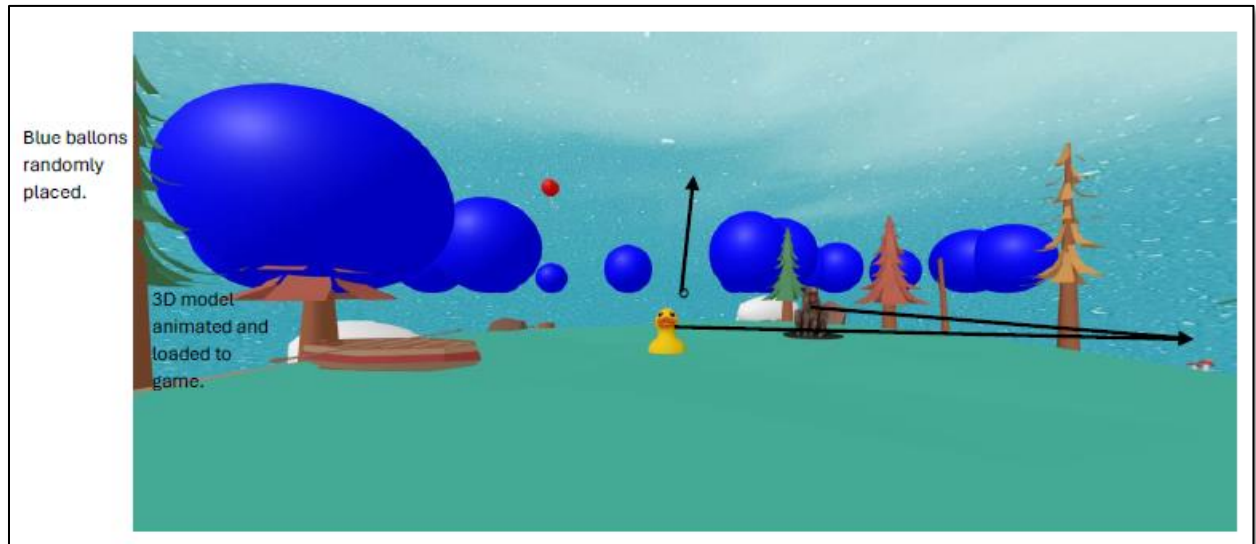
of 30 seconds. During the initial *15 s interval*, the user is immersed in a visual depiction of a lakeside forest environment featuring an animated yellow duck and a stationary monkey within the scene. Subsequently, at the *15 s mark*, a white duck is introduced, accompanied by the departure of the animals mentioned above.



**Figure 6.** The Instruction page

People with ADHD tend to get triggered by specific colour palates. Research and studies indicate that people with ADHD exhibit difficulties in colour differentiations. The dopaminergic neurotransmitter system's retinal mechanism is responsible for the short wavelength cone sensitivity: in a previous experiment stated in *Colour Perception in ADHD* (Journal of Child Psychology and Psychiatry<sup>[25]</sup>) it was noticed that children and adults with ADHD exhibit poorer performance on tests of colour perception, especially discriminating against blue colour. In this context, a German version of the Stroop-Colour-Word experiment was conducted on children with and without ADHD: participants were tasked with reading colour words, while in a second experiment, they had to name the colours of bars printed in these colours. Then, in a third scenario, participants were asked to name the colours of colour-words printed in incongruous colours. The findings outlined the fact that children with ADHD exhibit more errors, particularly with blue-yellow stimulation, indicating potential problems with the blue-yellow mechanism and changes in retinal dopaminergic mechanisms. It supports the colour perceptions that have changed in ADHD.





**Figure 7.** An overview of the VR game.

As shown in **Figure 7**, the blue balloons are randomly positioned in the 3D environment. The user is asked to hit the balloons by clicking on them. They are allotted 30 seconds to pop as many balloons as possible while maintaining a record of the burst balloons. Challenges the ADHD game in Mind Marvel offers to the player:

1. The task is to count the number of balloons popped. However, the environment is designed with many obstacles and distractions, such as animals' random appearance and movement in the game. In the game, two ducks and a monkey appear randomly on the scene.
2. The blue coloured balloons. As previously mentioned, if presented to the player, colours can trigger signs and symptoms.

At the end of the game, indications of ADHD are identified if presented in players through symptoms such as diminished attention, reduced concentration, and heightened susceptibility to distractions. The assessment section, followed by the game, aids the player in understanding their performance. Once the *20 s timeframe* is completed, the user is directed to the questionnaire page shown in **Figure 8**.

Question 1

How many balloons did you pop?


Question 2

Count the creatures, both animals and birds, that you have observed in the game.

- Three
- Two
- Not sure!

Question 3

Could you answer the color of the first duck appeared in the game?



**Figure 8.** Test your Marvelous Brain: the assessment section

Three questions are designed to assess the player's performance. The first question is regarding the number of balloons the user has popped, and it is to analyse their capacity to focus on an entitled task. The user is expected to enter integer values. Secondly, the game tests the individual's attention and focus level by questioning the number of animals spotted in the game. Finally, the user is examined to understand how easily they get distracted by small simulations. The user's answers are then analysed to explain their performance logically.

In order to play the game and navigate on the environment, the game was developed using React, A-Frame, and Three.js; therefore, it can be played on computer and VR devices that support these technologies. In computer devices, arrow keys or WASD keys in the keyboard are used to move around the surroundings. The mouse is used to look around the gaming environment. The user can see a black ring following the mouse on the scene. In virtual reality and 3D environments created with A-Frame, a cursor is often included to indicate where the user is pointing or looking. Ensure the black ring intersects with the object to click, drag, or move. It serves as a visual

feedback mechanism to help users interact with objects in the scene. In the platform, the A-frame library provides a framework to create a 3D environment and VR experiences that interact with objects using mouse clicks and keyboard controls. The mouse controls are configured inside the camera elements. Cursor behaviours like clicking and moving are defined in the attribute intersection span.

## Testing

When playing the ADHD game on the Mind Marvel webpage, the user is directed to an instructions page. The user can play the game from any browser using a mouse, keyboard, or VR controller. The user's task is to move around the environment and hit the blue balloons in the scene. They must keep track of the number of balloons they pop. Move back and forth in the environment to find the optimal angle for bursting the balloons.

The techniques employed to monitor user performance within the Mind Marvel system are detailed in **Figure 9**, which elaborates on the process of gathering data on balloon hits by the user. The platform is coded so that blue balloons are randomly generated in the scene at the start of the game. Each balloon is assigned a unique identifier consisting of a numerical value followed by the term 'balloon-'. Utilising a property from Three.js known as 'children. Length', the count of child elements within the scene is obtained. This count is then appended as the ID for each generated balloon using '*sceneRef.current.child.length*'.

```
balloon.setAttribute('id', `balloon-${sceneRef.current.children.length}`);
balloon.setAttribute('position', `${Math.random() * 10 - 5} 1 ${-Math.random() * 10}`);
balloon.setAttribute('static-body', true);
balloon.addEventListener('click', () => removeBalloon(balloon));

//Here, the balloon disappears when clicked
const removeBalloon = (balloon) => {
  setTotalBalloonsHit(prevHit => prevHit + 1);
  sceneRef.current.removeChild(balloon);
  play();
};
```

**Figure 9.** Code snippet of balloon hit method.

The event listener is attached to each balloon to facilitate user interaction through clicks. Upon clicking a balloon, a function is triggered to tally and store the balloon popped by the user in a variable. The balloon is simultaneously removed from the scene.

Thus, a function is developed to track the number of balloons the player hits. The accumulated data is then passed to the questionnaire section to analyse the user's performance.

### 3. Results

#### 3.1. Analyzing Player Performance

In the Mind Marvel project, the questionnaire section is the component where the player's performance is evaluated. The user is asked specific questions regarding the game and gaming environment. The answers are then analyzed to determine the presence of ADHD. The task is to hit the blue balloons in the scene and keep a count of them. In the game, balloons are the same size and color and are randomly placed in the environment. As mentioned before, the color blue can trigger ADHD symptoms in the player<sup>[2]</sup>. Viewing many blue-colored balloons can cause some difficulties for players in distinguishing them. Also, the environment is designed to distract the user from completing the task. The game has an immersive virtual lake environment with animals randomly appearing, disappearing, and simulating.

The following questions (**Figure 10** and **Figure 11**) focus on the relevance and functioning of the questionnaire:

##### **Question 1 - How many balloons did you pop?**

*Objective* - The question is regarding the number of balloons the user hits. The question tests the user's ability to focus on a given task. It also assesses their memory skill.

*Mechanism* - The user is asked to enter the number of hit balloons counted. The given answer is compared to the data obtained from the user's game. If the user fails to report the number of balloons accurately popped, it suggests potential challenges in maintaining attention and focus during repetitive activities. The animals and their simulations might have gained the attention of the player. People living with ADHD often demonstrate susceptibility to distraction, particularly in contexts involving detailed simulations. Also,

the color of the balloon can trigger the ADHD symptoms present in the individual. Those with ADHD often demonstrate susceptibility to distraction, particularly in contexts involving detailed simulations.

*Outcome* - Correct responses from the player signify strong attentional abilities and accurate information reports. The wrong response indicates the presence of a short attention span.

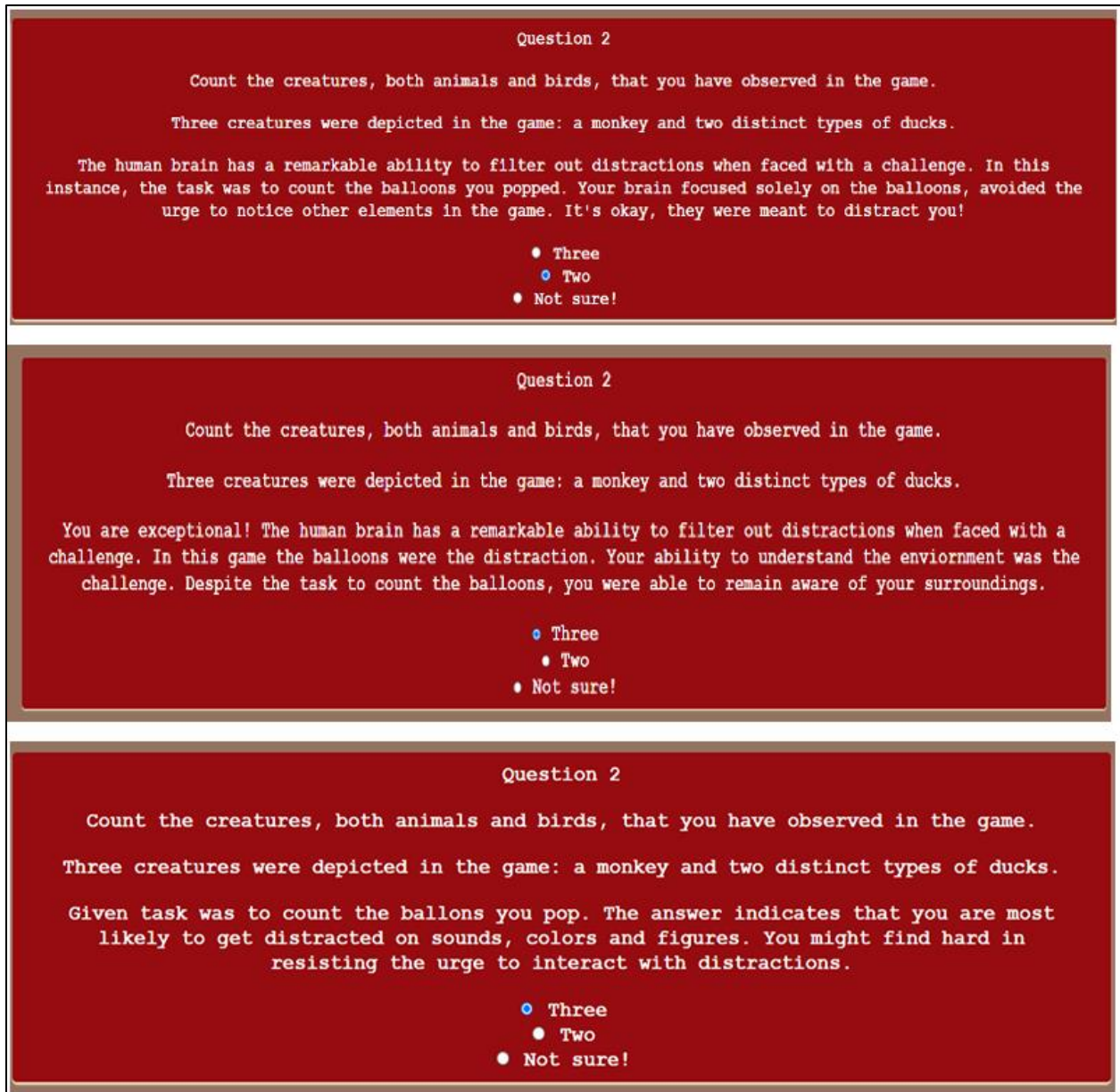


**Figure 10.** Response of *Question 1* vs right and wrong inputs.

**Question 2 - Count the creatures you have observed in the game, both animals and birds.**

*Objective* - The question aims to test the player's awareness of the environment and the ability to complete the given task. It also checks if the user is distracted by the surrounding simulations and sounds.

*Mechanism* - The VR environment in the Mind Marvel game is created with 3D animated models and sounds. These models offer users an immersive simulation of real-world scenarios while concurrently evaluating the player's ability to focus on completing the designated task. The use of animals as distractions introduces an element of impulsivity. People with ADHD cannot avoid external interactions to focus on the main task.



**Figure 11.** Possible response of the end-user when answering to *Question 2*.

Their tendency to impulsively engage with the animals can reflect impulsivity, which is another common ADHD symptom. When requesting the user to recall the VR game scene, the game assesses their awareness of their virtual surroundings. The user is given three options and asked to pick the correct answer. Question 2 can only be answered after answering question 1. The answer provided by the user can determine the presence of ADHD depending on the answer they provided for question 1.

*Outcome* - If the player correctly numbers the popped balloons and gives the correct number of animals visible in the game, their brain successfully focuses on the assigned task and can remain aware of the surroundings. The player demonstrates commendable attentional prowess, exhibiting strong focus and an impressive capacity to recall past information. If the player correctly numbers the popped balloons but cannot recall the animals viewed in the game, it indicates that their brain is solely focused on the given task. The human brain can filter out distractions when faced with a challenge. In this instance, the task was to count the balloons that popped. The player focused solely on the balloons and avoided the urge to notice other elements in the game. However, if the player fails to complete the task but accurately identifies the number of animals, it indicates impulsivity, a characteristic often associated with ADHD. The player's focus is shifted from the primary task to the distraction. Individuals with ADHD may struggle to avoid external distractions, impacting their ability to maintain focus on specific tasks.

### **Question 3 - Could you answer the color of the first duck that appeared in the game?**

*Objective* - The question checks if the player gets distracted by simulations and small movements in the game. The final question explains the deviation of the player's focus from the primary task to distractions.

*Mechanism* - The game has two ducks appearing at different times. At the start of the game, a yellow duck keeps moving in the scene. After 15 seconds, a white duck appears in the game. This mechanism is designed to distract the player from counting the popped balloons. The sudden appearance and disappearance of objects in the scene can gain the player's attention, hindering them from recalling the information.

*Outcome* - If the user correctly answers the color of the duck, it indicates that the user had a gaze on the altering simulations in the scene. If the user fails to answer the color of the duck, it indicates that their brain is solely focused on the given task.

## **3.2. Results**

Once the user performance is recorded, an appropriate result is delivered to them. The game aims to highlight potential signs and symptoms of ADHD present in the player. By observing gameplay behavior and performance, users can gather valuable information about their attentional control, impulsivity, sensory processing, and executive functioning, all relevant to ADHD diagnosis and management. Nevertheless, it is crucial to note that the Mind Marvel game does not diagnose ADHD but functions as a screening tool. This tool employs a brief questionnaire comprising only three questions with a limited range of responses to analyze performance. This analysis section scrutinizes these restricted responses to identify potential indicators of ADHD. The game analyses player responses within the questionnaire section and generates one of two possible results based on the answers provided. **Table 3** illustrates the relationship between player responses and the corresponding outcome.

**Table 3.** Analysing the possible answers to generate appropriate results

<p><b>The Mind Marvel game generated two reports based on user performance</b></p>	<p><b>Result 1:</b> The result from the assessment suggests that the symptoms of ADHD are present in the player.</p>		<p><b>Result 2:</b> The result from the assessment suggests that the player has excellent attention skills and good vision.</p>
<p><b>Answers for Question 1 to receive the corresponding report</b></p>	<p>The user failed to answer the correct number of balloons popped.</p>	<p>ADHD Symptoms found</p> <ul style="list-style-type: none"> <li>• Short attention span</li> <li>• Distraction to simulations</li> </ul>	<p>The user correctly answered the number of balloons that popped.</p>
<p><b>Answers for Question 2 to receive the corresponding report</b></p>	<p><i>Scenario 1</i></p> <p>Correctly answered the number of animals but failed to answer the number of balloons</p>	<p>ADHD Symptoms found</p> <ul style="list-style-type: none"> <li>• Impulsivity</li> <li>• Lack of attention</li> <li>• Easily distracted</li> <li>• Shifting focus from the primary task</li> </ul>	<p>The user has entered the correct number of balloons that have popped. The number of animals entered can be right or wrong.</p>
	<p><i>Scenario 2</i></p>		



	The user entered the wrong answer for both questions		
<b>Answers for Question 3 to receive the corresponding report</b>	The user typed 'white' instead of yellow.	ADHD Symptoms found <ul style="list-style-type: none"> <li>• Shifting focus from the primary task to surrounding movements</li> </ul>	The user entered 'yellow'.

#### 4. Discussion




This work explores the effectiveness of a game-based approach towards neurological disorders such as ADHD. A novel platform – i.e. the Mind Marvel – has been presented: the system integrates a website design with a VR-based game. The architecture of the system and the strategies behind the selection of certain technological have been presented and supported with evidence from previous studies. A preliminary set of experiments in order to validate the system have been also performed, even if a clinical validation has not be achieved at this stage.

The development of the platform was driven by identifying and addressing any potential ADHD symptoms exhibited by players. The complete application was crafted to encompass three primary aspects of an ADHD game: task-oriented focus, educational attainment, and identification of neurological conditions, as outlined before<sup>[13]</sup>. Mind Marvel website provides a task-focused ADHD game in a dynamic VR environment to engage the player’s brain to focus and maintain attention. By challenging users to pop as many balloons as possible within a 30 s interval, the game aims to improve their performance, attention, and perceptual abilities. Set against a backdrop of dynamic surroundings featuring vibrant colours, animated characters, and background audio, the game evaluates the player's attention span, impulsivity, hyperactivity, and concentration. The user's performance outcome serves as an indicator of potential ADHD symptoms. Mind Marvel's website offers an educational page on ADHD awareness. It provides insights into understanding ADHD, its signs and symptoms, and shared facts about the condition. The website is structured to deliver knowledge about ADHD with ease, ensuring that users can access information about

ADHD with a single click. The interactive backgrounds on the page are crafted to provide a fun engagement experience and raise awareness about ADHD. Users are prompted to answer a question designed to gauge their attention level, thus encouraging self-awareness regarding their cognitive focus. Once the game is over, the player's performance is analysed to generate an appropriate outcome regarding ADHD symptoms. Hence, the project successfully reflects the perspectives presented by Craven, Michael P., et al<sup>[13]</sup>. Following an analysis on ADHD and digital games, two existing games were analysed and documented in **Table 4**: the table highlights the essential features of an ADHD game and lists the games that offer them. A comparison of the pre-existing games, *Snappy App* and *EndeavorRx*, with the *Mind Marvel* platform is drawn.

**Table 4.** Comparison of the Mind Marvel's performance vs other two ADHD games, namely Snappy App and EndeavorRx

Features offered by the game	Importance of the feature	Games that offer this feature	
ADHD Awareness Page	<ul style="list-style-type: none"> <li>Aid the player in understanding the signs and symptoms of ADHD.</li> <li>Despite the prevalence of ADHD, a significant portion of individuals remain unaware of their condition.</li> </ul>	Snappy App	✓
		EndeavorRx	✗
		Mind Marvel	✓
About Page	<ul style="list-style-type: none"> <li>Describing the purpose of the app.</li> <li>Players are aware of how that app serves as a medium in the context of ADHD.</li> </ul>	Snappy App	✓
		EndeavorRx	✓
		Mind Marvel	✓
Instruction Page	<ul style="list-style-type: none"> <li>Explains the functioning of the app.</li> </ul>	Snappy App	✗
		EndeavorRx	✓
		Mind Marvel	✓
Accessibility	<ul style="list-style-type: none"> <li>The game must be available to all the people via all devices.</li> </ul> <p>Snappy App and EndeavorRx are mobile applications, while Mind Marvel is a web application. Web applications can be accessed from any device via a browser.</p>	Snappy App	✗
		EndeavorRx	✗
		Mind Marvel	✓
Analyse and Report	<ul style="list-style-type: none"> <li>The game analyses the player's performance, generating an appropriate report.</li> </ul>	Snappy App	✓
		EndeavorRx	✓
		Mind Marvel	✓

	<ul style="list-style-type: none"> <li>• Players are informed about their cognitive skills level and the assessments made by the user.</li> </ul>		
Providing medical support to ADHD people	<ul style="list-style-type: none"> <li>• If the app identifies the presence of or signs of ADHD in the player, providing a medical/clinical helping hand is essential.</li> <li>• Further steps are advised to the player.</li> </ul>	Snappy App EndeavorRx Mind Marvel	  

**Table 4** delineates the requisite features and functionalities for an ADHD-oriented game. The Mind Marvel game has incorporated most of these elements. Like Snappy App and EndeavorRx, Mind Marvel is a sophisticated game crafted through meticulous research and employing highly recommended methodologies. The table above illustrates how the game effectively functions as a suitable ADHD intervention like the other two applications.

The Mind Marvel website provides users with a Virtual Reality experience through its ADHD game. The game offers the user an immersive experience of real-world scenarios of a lake. It also tests the player’s cognitive skills, like recalling information, decision-making, problem-solving, and concentration skills. With the dynamic environment, the game was able to expose the presence of ADHD signs like short attention spans, distractions to simulations, carelessness, and short memory if present in the player. Pleasant backgrounds and soothing soundtracks in the game have induced emotions and raised the potential psychological conditions.

There are clearly other implications from this work which involves also other types of technologies such as, for example, Virtual Reality and wearable technologies: more informative platforms could be designed where the proposed systems integrated with VR interfaces combined, for example, with wearable sensors which may be used in order to detect (and trigger) data acquisition. For instance, the detection of meltdown events or other significant episodes, such as stress episodes could then activate (or de-activate) a specific set of VR environments or, in the context of this work, a different set of questions.

## 5. Conclusion

In this paper we have presented the Mind Marvel platform, a system combining the design of a website with the implementation of a VR game. A set of preliminary tests have shown the useful potential of the platform in order to detect and support ADHD. Nevertheless, a proper clinical validation of the system with a refinement of the characteristic of the proposed platform would be beneficial in the future.

After conducting comprehensive research into ADHD, a deeper understanding was obtained of the signs and symptoms, treatment modalities, diagnostic procedures, and underlying causative factors. Identifying the early signs of impulsiveness and hyperactivity in children can help control this neuro disorder and channel the energy into building a better life for them<sup>[26]</sup>. Genetics or environmental factors can play a significant role in ADHD, but still cannot avoid the occurrence of it in individuals. Improving cognitive skills along with medical interventions can aid people living with ADHD in recovery<sup>[27]</sup>. Undertaking a study on this neuro disorder opened the path to explore the importance of digital video games as a treatment or diagnosis tool. Video Games can improve players' cognitive functions, focus, multi-tasking, stress management, and thinking skills, enhancing ADHD.

The Mind Marvel Platform provides a VR game with a dynamic environment and challenging tasks to assess the presence of ADHD symptoms in the player. The app assesses the performance and provides feedback to the user. Research and studies backups the fact that:

- VR can train cognitive skills<sup>[28,29]</sup>.
- VR games like EndeavourRx are used as a prescribed treatment method as they help to identify the underlying symptoms of ADHD in people.
- VR environments and simulations can provide a soothing effect on players by reducing stress, depression, fatigue, and anxiety.

Although this work aids in identifying symptoms of ADHD and advocates for the condition, there are potential enhancements for future updates of the Mind Marvel application. To effectively address ADHD, collaboration with clinicians, psychologists, and medical teams in the design and construction process is imperative together with the choice of the proper technologies<sup>[30-32]</sup>. While extensive research assisted the development process of the ADHD game, the advice of clinicians

and the medical team would have enhanced the overall functioning of the application. Additionally, automated reporting of player performance to clinicians and guidance on the next steps following ADHD detection could be integrated. Using video games as a treatment method can also negatively impact the player. People with ADHD are impulsive and hyperactive; therefore, there is a chance of developing an addiction to these games. Future iterations of the proposed system could investigate methods and technological solutions to alleviate the adverse effects of digital ADHD games on players<sup>[33-36]</sup>. Mind Marvel has successfully demonstrated its potential as an intervention for identifying ADHD signals in players. Furthermore, it has underscored the significance of raising awareness about ADHD among the public by offering a platform for disseminating ADHD-related information to all its users.

According to a multi-disciplinary approach and to the available technologies, it would be interesting to integrate the Mind Marvel platform with a set of other solutions inherited from, for example, the engineering and computer science background of the working team behind this work: wearable sensors can provide important physiological information about the performance and physiological status of subjects while performing the tasks under the Mind Marvel platform<sup>[37-39]</sup>. Moreover, an analysis of these sensorial information combined with Machine Learning techniques could support the detection of stress conditions associated (or not associated) with the tasks<sup>[36]</sup>. Such an integrated approach would benefit of a clinical validation where the system is compared with a set of measurements performed with golden standard equipment<sup>[40]</sup>

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### **Author contributions**

*Conceptualization:* Noyal Babu1, Neil Buckley

*Investigation:* Noyal Babu1

*Methodology:* Noyal Babu1, Neil Buckley

*Formal analysis:* Noyal Babu1

*Writing – original draft:* Noyal Babu1, Emanuele Lindo Secco

*Writing – review & editing:* Emanuele Lindo Secco

### **Ethics approval and consent to participate**

Not applicable

### **Consent for publication**

Not applicable

### **GitHub Repository**

The entire development process of the Mind Marvel web application is recorded, and versions are tracked inside the GitHub repository. Visit the link to the repository:

[https://github.com/Noyalbabu/Dissertation\\_Implementation](https://github.com/Noyalbabu/Dissertation_Implementation)

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