Neurofeedback Ball Game Using Neurosky Mindwave Based on Attention Level

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Abstract. EEG is widely used for brain imaging due to its affordability and simplicity. NeuroSky's single-channel sensor is favored by researchers for its non-invasive nature, capturing brainwaves at a single head location to acquire EEG signal data.This paper presents an EEG-driven gaming interface in which the subject's attention is utilized to effectively control the game. This game employs a ball that moves from the starting line towards the finish line according to the player's level of attention. The game is played by two players, one of whom is a mini-computer utilizing a Raspberry Pi. The design of this ball game using EEG is more portable and offers a genuinely interactive experience without utilizing a game display on a monitor screen. The results of this study indicate that the developed system can demonstrate changes in player attention, resulting in corresponding movements in the ball's displacement as per the design. Future steps involve assessing the game's usability for enhancing focus abilities.

Keywords: EEG, Neurosky, Attention, Portable, Raspberri Pi

1 Introduction

Electroencephalography (EEG) is a non-invasive technique used to record the electrical activity of the brain. By placing electrodes on the scalp, EEG captures the patterns of neural firing, providing valuable insights into brain function and cognitive processes [1]. In recent years, EEG technology has witnessed remarkable advancements, propelling it to the forefront of various fields. Researchers are leveraging EEG to explore brain-computer interfaces (BCIs), allowing direct communication between the brain and external devices. Furthermore, the use of EEG has become very extensive. Numerous research studies have employed EEG signals to classify directional imagination [2]–[5] comprehend the emotional and cognitive responses of consumers towards products to enhance marketing strategies [6], [7] and detect alertness and fatigue in drivers [8]. Moreover, the utilization of EEG in the field of healthcare has also progressed rapidly, such as its application in sleep disorder detection [9], mental health [10][11] [12] the identification of neurological disorders like Alzheimer's [13], and so forth.

In line with the availability of portable and affordable EEG devices, the applications of EEG have expanded to include game development aimed at enhancing focus and patient rehabilitation in the healthcare field. A study [14] utilized right and left buttons to assist in selecting answers

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to questions displayed on a monitor screen. Users were required to concentrate in order to move the cursor towards the right or left button choice. The testing was conducted over 5 days to observe improvements in answer accuracy correlating with increased concentration scores. However, this method is less portable as it necessitates the use of a Personal Computer for implementation.

Research [15] and [16] utilized EEG signals generated from eye blinks. Study [15] involved using eye blinks to select the direction of chess piece movements. Conversely, study [16] employed eye blinks to collect fruits into a basket. A drawback of [15] is its limitation to those who can play chess, making it less universally applicable. Furthermore, both [15] and [16], which developed blink-based games, are susceptible to noise or errors due to human blinking caused by dry eyes.

In [17], the developed game was memory-based, where players were tasked with memorizing numbers within a matrix and attempting to correctly refill the matrix. The purpose of this game was to enhance concentration rather than entertainment. Study [18] similarly aimed to improve player focus through the use of wearable EEG and virtual reality (VR) in patients with ADHD and ADD. The employment of these two devices results in relatively high costs and more complex computations. In research [19], VR and the neurosky mindwave device were employed. Common challenges faced included player discomfort and higher costs.

Studies [20][21][22] employed ball-based game concepts. Research [20] created a ball game playable against a computer using the Emotive sensor. This game quantified attention levels by calculating the theta and beta signal ratio. Players were required to concentrate in order to move the ball from one point to another. While interactive gameplay against a computer is engaging, portability and comfort levels are reduced due to the need for a computer and Emotive sensor with multiple measurement points on the player's head. Research [21] also utilized a computer to display a ball-based game, where forward movement depended on concentration while turning was triggered by eye blinks. A drawback was the requirement for a computer monitor display. Meanwhile, research [22] employed a two-player concept similar to [20] but eliminated the need for a computer. This game utilized a large table to create a path for the ball to move towards the opponent if the player's attention surpassed the opponent's. The advantage of this game over its predecessors was the reduction of the monitor display requirement, eliminating the need for a computer. However, the elongated table made this game less portable.

In [23], it is mentioned that the challenges in EEG-based game development revolve around portability and the complexity of game design. Therefore, to address the issues raised in the aforementioned studies, this research proposes a ball-based game that employs attention from EEG signals acquired through the Neurosky Mindwave sensor, involving two players, but without the need for a monitor display, utilizing a smaller and simpler design for improved portability and real interactivity.

2 Research Methods

This study underwent several stages, including needs analysis, system workflow design, hardware design, system implementation, and system testing.

2.1 Design and Working System of the Device

In designing a system, a block diagram is essential to illustrate the overall functioning of the system, ensuring it operates as intended. Figure 1 presents the designed system's block diagram.

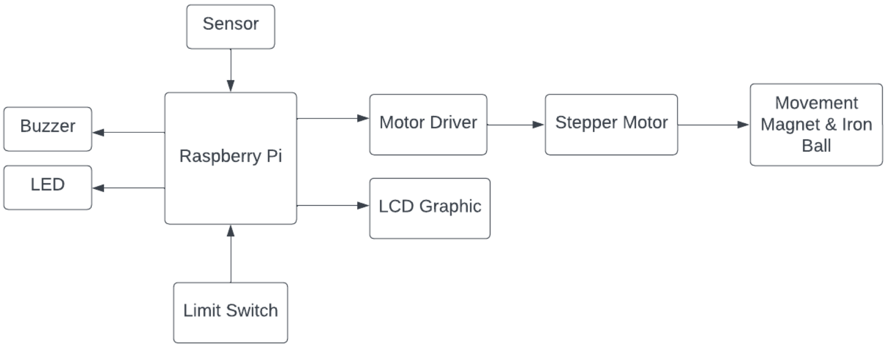

Fig 1. Block diagram of the system

The system comprises a Raspberry Pi, limit switches, magnets, LEDs, and a buzzer. In this system, the attention score derived from EEG signals acquired using the Neurosky Mindwave sensor serves as input for the microcontroller. The received attention score data is then processed to generate a motion value for the ball, which is transmitted to the DRV8825 motor driver. The Raspberry Pi triggers the motor driver to control the stepper motor's movement. The limit switches determine the presence of objects on the game path and ascertain if a player has reached the finish line. The limit switch is activated upon contact or pressure from the magnet, halting the stepper motor's movement. The magnet's function is to attract the iron ball located outside the device's path, guiding its movement according to the calculated attention score. In the mechanical design, the stepper motor is connected to a permanent magnet positioned beneath the ball's movement path. Since an iron ball is used, its forward movement is influenced by the magnet's movement, controlled by the player's attention score. A higher attention score results in a greater ball movement distance.

The stepper motor's movement is categorized into various patterns, where the attention score is divided into multiple ranges to determine the stepper motor's angle of movement. This, in turn, affects the ball's movement towards the finish line. Table 1 displays the relationship between attention score ranges and stepper motor movement. The minimum attention score required to move the ball is 40. A similar concept is applied to the stepper motor movement generated by the player, who uses the Raspberry Pi mini-computer. Randomly generated attention score ranges also have a similar impact on the ball's movement.

Table 1. Stepper Motor Movement Design Based on Attention Score

Attention Score	Motor Stepper Rotation (˚)
40-50	11.25
50-60	22.5
60-70	33.75
70-80	45

80-90	56.25
>90	68

The mechanical system of this EEG-based ball game consists of two separate paths, where each player uses a different path to control a distinct ball. The use of two distinct paths allows for a shorter playing table or area. The device's design is depicted in Figure 2, showcasing a 50 cm ball track engraving. However, the start and finish lines only span 30 cm, making the player's track length 30 cm.

The opponent's attention value, represented by the Raspberry Pi mini-computer, is randomized. The winner of the game is determined by the player who successfully moves their ball to the finish line before their opponent. The winner and the attention scores of both players are displayed on an LCD screen. When a player's ball reaches the finish line, the LED and buzzer become active. After the game concludes, the balls return to their initial positions. The flowchart outlining the functioning of this ball game system is illustrated in Figures 3-5, while the wiring diagram design can be seen in Figure 6.

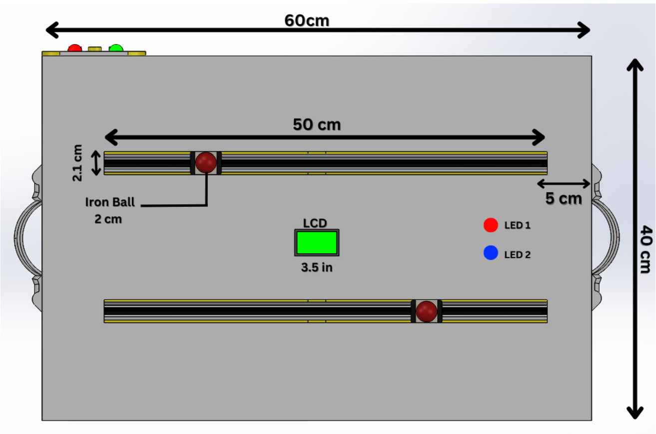

Fig. 2 Device Design

From the flowcharts in Figures 3 and 4, it is evident that the ball's movement design based on attention adheres to the design in Table 1, both for players and the computer opponent (COM). Figure 5 demonstrates the functions of the limit switches, LEDs, and buzzer. Each player's finish line is equipped with a respective limit switch, with Limit Switch 1 on the player's path and Limit Switch 2 on the COM's path. When a player's ball touches the finish line, triggering the magnet inside the device to engage the limit switch, LED 1 lights up, along with a 10-second buzzer activation. The LCD then displays the player as the winner. Similarly, if the COM's ball crosses the finish line, LED 2 and the buzzer illuminate, and the LCD shows the COM as the winner. Once the game concludes, both balls return to their start position, controlled by Limit Switches 3 and 4.

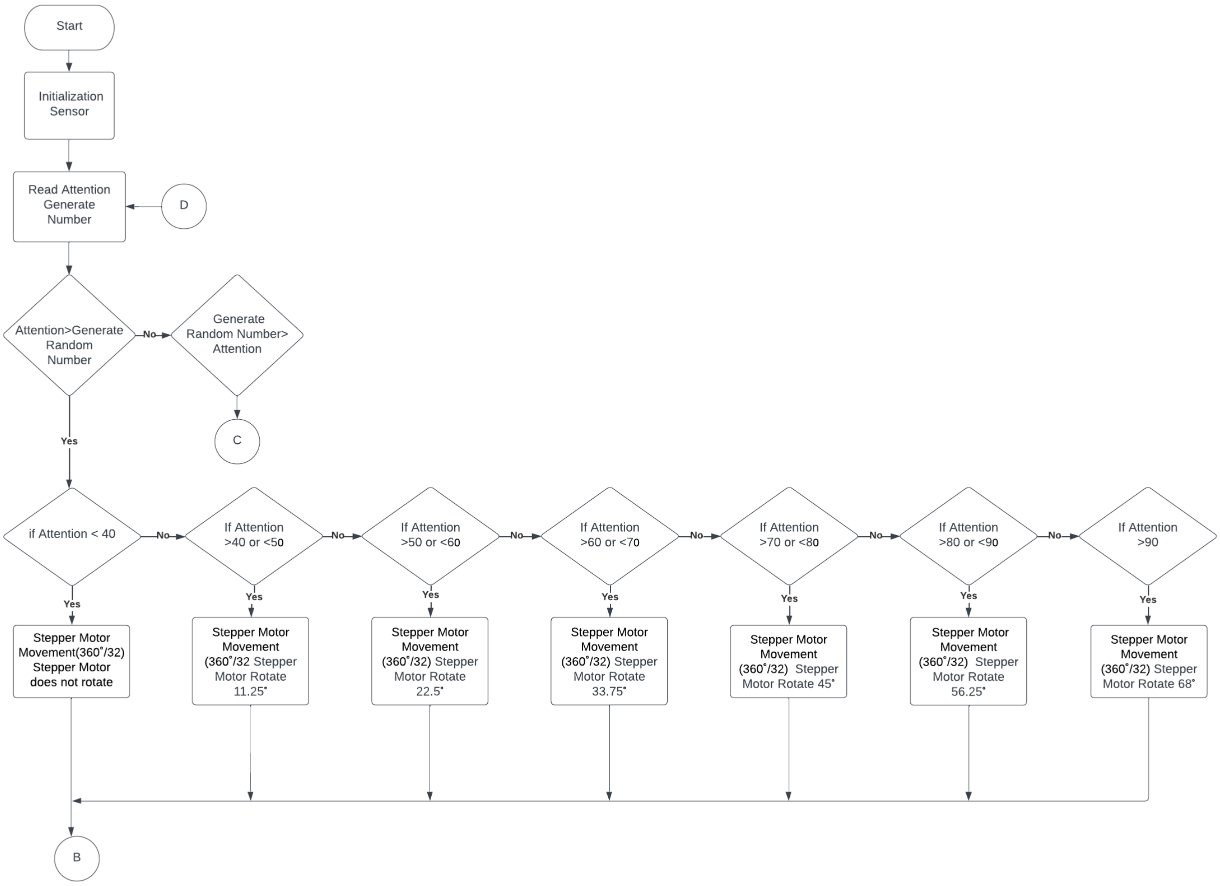

Fig 3. System Flowchart for Player

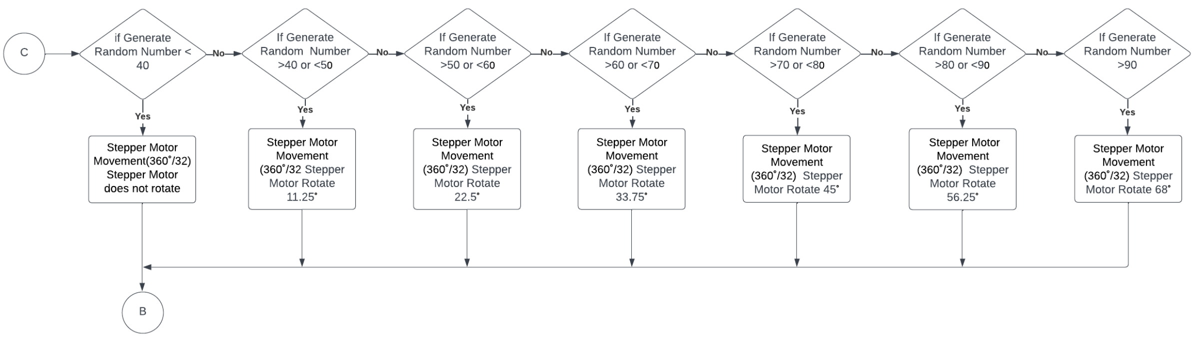

Fig 4. System Flowchart for COM

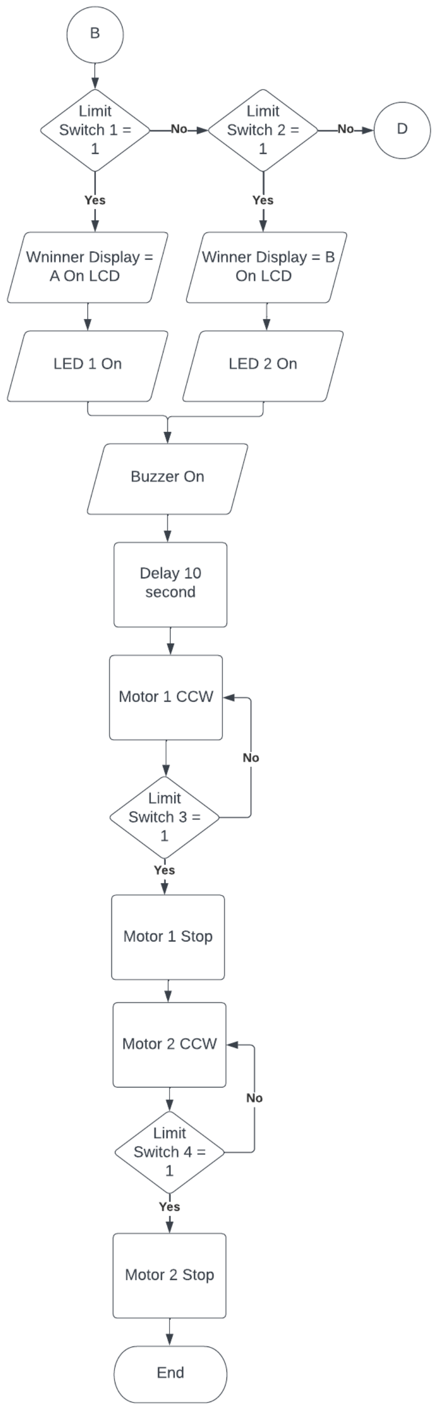

Fig 5. Flowchart of the system interface

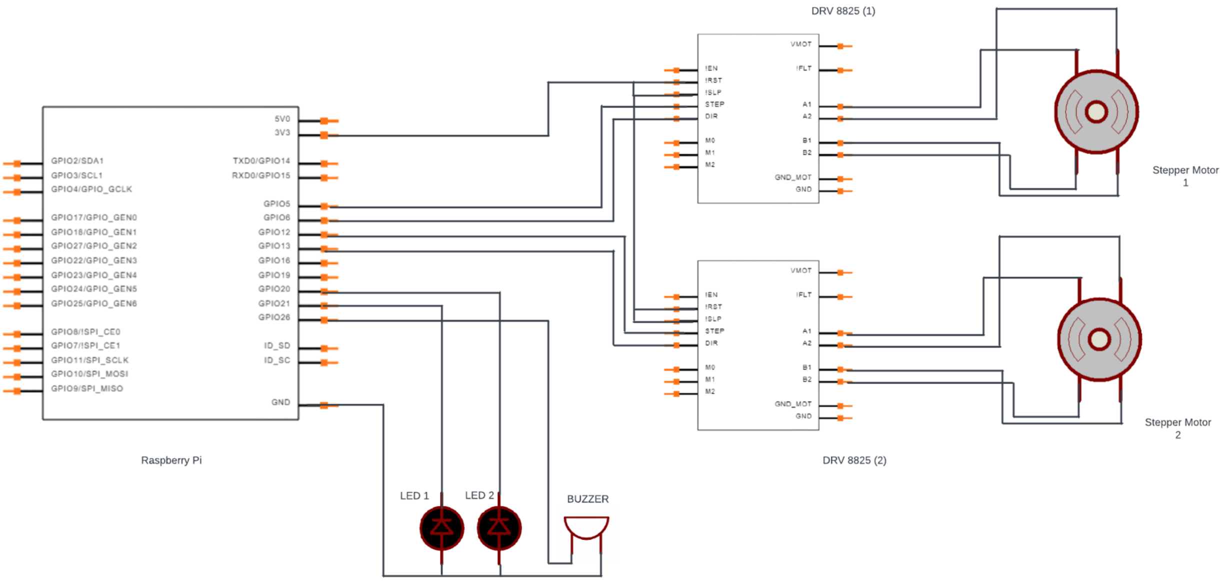

Fig 6. Electronic Circuit Design

3. Result and Discussion

The results of the device design and its operational system will be explained in this section. Testing for ball movement and the LCD display will also be demonstrated in this section. Figure 7 presents the outcome of the created portable ball-based gaming device. The dimensions of this device are 60 cm x 40 cm x 25 cm. The internal components within the device enclosure can be observed in Figure 8.

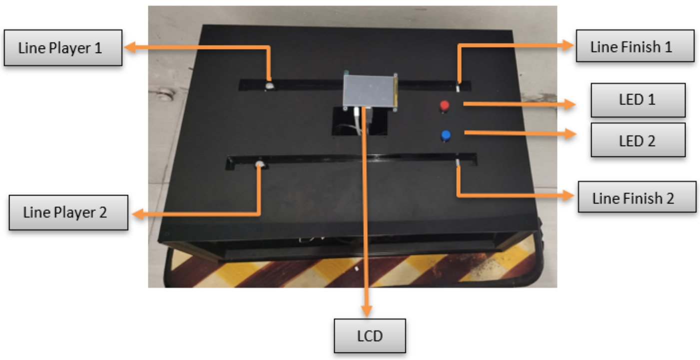

Fig 7. EEG Signal-Based Ball Game Device

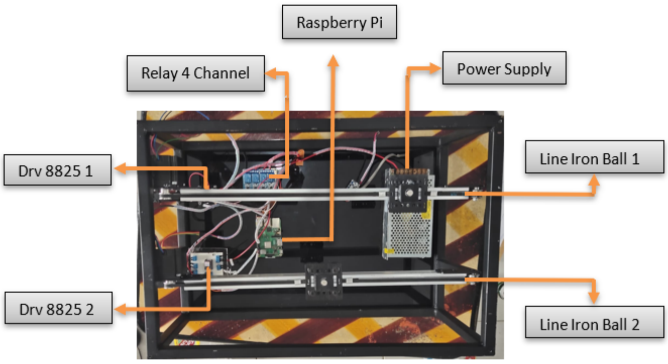

Fig 8. Internal View of the Device

3.1 Ball Movement Testing

The first test was conducted to determine the distance of ball movement based on the attention scores and the angle of stepper motor movement previously designed. Table 2 presents the ball movement distances corresponding to attention scores and the angle of stepper motor rotation. From the measurement results, it is evident that as the attention score and motor rotation angle increase, the ball's movement distance also increases. Thus, a player generating a higher attention score will lead to a faster ball movement towards the finish line.

Table 2. Ball Movement Distance Testing

Attention Score	Motor Stepper Rotation (˚)	Ball Movement Distance (mm)
40-50	11.25	2
50-60	22.5	4
60-70	33.75	6
70-80	45	8
80-90	56.25	10
>90	68	12

3.2 Attention Display and Winner on LCD

During the gameplay, the attention scores of both the player and the Raspberry Pi mini-computer (COM) will be displayed on the LCD, as shown in Figure 7. Once a player reaches the finish line, the winner's name will also be displayed on the LCD screen, as depicted in Figure 8. In Figure 7, it is evident that the random value displayed as the COM's attention score can also have a value below 40, indicating that the COM's ball did not move at that time. To win the game, the non-COM player must maintain their attention score at a high value, allowing their ball to continue moving.

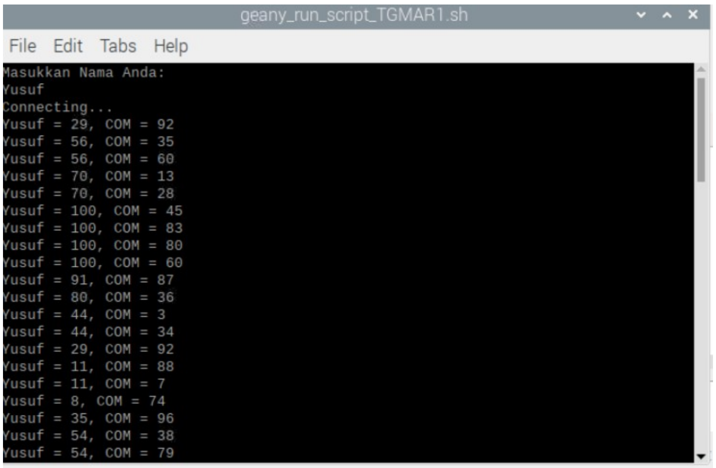

Fig 7. Player's Attention Display on LCD

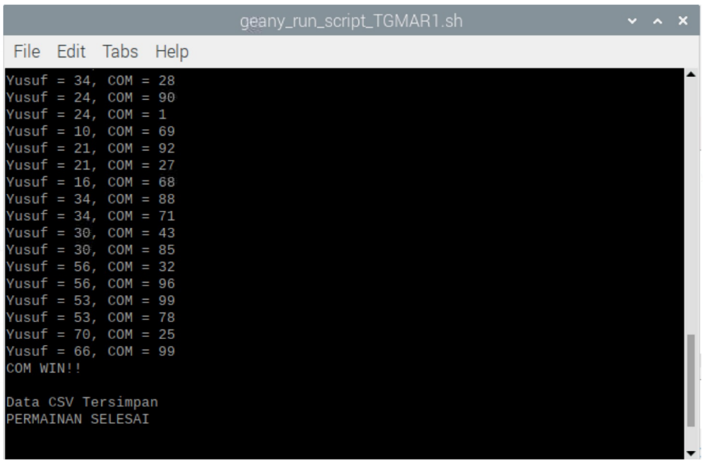

Fig 8. Winner Player's Display on LCD

3.3 System Testing During Gameplay

In this section, testing will be conducted during gameplay, where Table 3 demonstrates the changing attention scores of both players and the movement angles of the stepper motor. Meanwhile, Table 4 illustrates the calculation of game duration. In Table 3, attention data and ball movement are measured during the gameplay. The presented data is a subset of the overall dataset. The total data collected during the game consists of 74 data points, and when the ball movement distances are summed, they equate to the track length from the start line to the finish line, which is 300 mm. In this data collection, the winner was the COM player.

Table 3. Attention and Ball Movement Test

No	Attention		Player's Ball Movement Distance(mm)	COM's Ball Movement Distance(mm)
	Player	COM		
1	29	92	0	12
2	56	35	4	0
3	56	60	4	6
4	70	13	8	0
5	70	28	8	0
6	100	45	12	2
7	100	83	12	10
8	100	80	12	10
9	100	60	12	6
10	91	87	12	10
11	80	36	10	0
12	44	3	2	0
13	44	34	2	0
14	29	92	0	12
15	11	88	0	10
16	56	32	4	0
17	56	96	4	12
18	53	99	4	12
19	53	78	4	8
20	70	25	8	0
21	66	99	6	12
22	56	0	4	0
				COM WIN

3.4 Ball Game Testing Based on Game Duration

The following test involves measuring the gameplay duration until reaching the finish line. The following Table 4 displays the attention scores of the two players with different attention values, along with the time required to reach the finish line. This table represents the testing of the game based on game duration. The data provided is a portion of the total dataset, consisting of 115 data points for Player 1 and 78 data points for Player 2. From the collected data, it can be observed that Player 1 required approximately 75 seconds to reach the finish line, experiencing 23 instances of attention scores below 40, resulting in the ball not moving. Player 1's average attention score falls within the range of 40-50, with a stepper motor angle of 11.25 degrees, causing the iron ball to move only 2 mm.

On the other hand, Player 2 only needed 56.61 seconds to reach the finish line. This is attributed to their average attention score falling below 40 only 3 times. Player 2's average attention score falls within the range of 50-60, causing the stepper motor to rotate 22.5 degrees, resulting in the iron ball moving 4 mm. The graph in Figure 9 illustrates the changes in player attention during each data collection. From the graph, it's evident that Player 2 consistently maintains focus and generates higher attention scores, allowing them to complete the game more quickly. Meanwhile, Player 1 has relatively lower attention scores, leading to a longer time required to reach the finish line.

Tabel 4. Game Duration Test

No	Attention		Ball Movement of Player 1	Ball Movement of Player 2
	Player 1	Player 2		
1	43	56	2	4
2	41	56	2	4
3	41	56	2	4
4	40	56	2	4
5	40	47	2	2
6	27	47	0	4
7	27	47	0	4
8	38	50	0	4
9	38	50	0	4
10	40	57	2	4
11	40	57	2	4
12	41	74	2	8
13	63	66	6	6
14	63	69	6	6
15	64	67	6	6
16	81	63	10	6
17	88	63	10	6
18	88	66	10	6
19	90	66	12	6
20	77	70	8	8
21	77	60	8	6
22	77	60	8	6
23	56	61	4	6
24	67	54	6	4
25	69	54	6	4
26	51	53	4	4
27	57	67	4	6
	Play time		75 sec	56, 61 sec

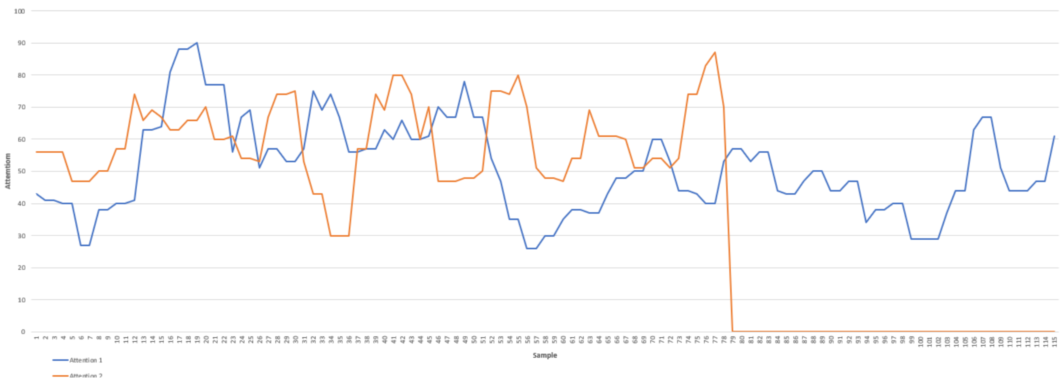

Fig 9. Comparison of Attention between two Players

4. Conclusion

Neurofeedback games show significant promise in aiding the enhancement of an individual's focus level. The outcomes of the designed EEG-based ball game device offer ease of use and portability. The utilization of a physical ball track imparts a distinct experience compared to playing ball games on a monitor, which could strain the eyes. This tool effectively illustrates changes in attention and measures the players' game completion speed. As a future development, the device will be implemented on multiple subjects to assess whether this game can contribute to improving users' attention levels.

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