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# Virtual Character Control by Brain-Computer Interface and Comparison of Performance Metrics

1st Caner GEZGEZ
*Advanced Technologies Center*
*Havelsan A.Ş.*
Kocaeli, TURKEY
orcid.org/0000-0003-4500-9386

2nd Elif KAÇAR
*Department of Physics*
*Department of Electro-Optical System Engineering*
*Kocaeli University*
Kocaeli, TURKEY
orcid.org/0000-0001-6682-0114

***Abstract*—Brain-Computer Interface (BCI) is a communication system that allows to create interfaces between the human brain and artificial devices. With the advent of consumer grade EEG devices, BCI-controlled games began to be designed. The designed games have features that can be evaluated in the category of competitive games in the entertainment sector and serious games in the medical domain.**

**In this study; two level 2D game was designed that includes single and multi tasking, which provides virtual character control with both BCI and HCI. Two dissimilar BCI prediction algorithms were used in this game designed using a game engine that supports many platforms. Performance metrics obtained from our experiments designed using the developed game for two different methods, estimation algorithms and levels were compared each other.**

***Index Terms*—Brain-Computer Interface (BCI), Multitasking, Electroencephalography (EEG), Emotiv Epoc+, Mind Controlled Game.**

## I. Introduction

Brain-Computer Interface (BCI) technology is a rapidly growing domain and studies on this technology are increasing. The most known applications of BCI technology are to provide a new communication interface for paralyzed patients / motor disabilities [1]. In addition, although the developed BCI controlled games seem to serve the entertainment industry, they produce information worth evaluating in terms of clinical neurological feedback studies [2]. On the other hand, development of serious games, whose primary purpose is not entertainment but teaching, has become even more efficient with developing technologies such as mixed reality, virtual reality, augmented reality, simulation and BCI [3, 4].

BCI controlled games that can be evaluated in the serious games category are developed primarily with applications on healthy individuals. In this process, BCI allegedly replacing the Human-Computer Interaction (HCI) [5], to validate this claim, BCI needs to interpret and predict brain activity into meaningful commands that allow for smooth gameplay. On the other hand the reason for the delays that will occur in this cycle should be investigated and the solutions found should be stated in the literature [6]. In the creation of these commands; it is important to realize prediction algorithms for games, to examine them on the desired single and multitasking and to compare the performances. Device selection is as important as the selection of estimation algorithms for examining these tasks. The most popular of these devices are "NeuroSky MindWave" and "Emotiv Epoc" devices. It has been shown that the "Emotiv Epoc" device, which is preferred in non-critical applications such as games, gives more reliable information in performance measurement [7]. It also revealed that it is more effective in terms of consistency and interaction in serious games. These devices are widely used in scientific research due to their signal quality comparable to medical grade devices [8].

Developing games in which both HCI and BCI methods can be applied and evaluating their usage performance in healthy individuals; provides evaluable information in the development of serious BCI-controlled games [9]. A game called "Bacteria Hunt" with multiple tasks; keyboard hardware, which has an important place for HCI, has been developed in accordance with the SSVEP and Relative Alpha Power methods, which are the BCI prediction paradigm [10]. In this game, which has three different gameplay modes, BCI methods were used as an aid and the performance of HCI and BCI use was evaluated. In another game has multitasking, it provided virtual character control both the keyboard with HCI hardware and the BCI prediction method Lateralized Readiness Potential and the performances of the methods were compared [11]. Examples of these games developed under BCI control are "MindBalance" [12], "Pinball" [13], "Tetris" [14] and "World of Warcraft" [15]. Among these studies, Tetris game was developed as BCI controlled to be tested in pilot experiments with children with attention deficit and hyperactivity disorder, and it has been shown that it can be effectively controlled in healthy individuals [14]. It has been reported that with the BCI controlled Pinball game developed as a platform to examine the timing and dynamics of brain control, data that will contribute to future research of mental states during real-time tasks and decision-making processes [13].

The first users of applications developed with BCI, if there is a technology that can provide functionality without significant setup time or hassle, those who like to play games. The second generation adopters will also be sectors that spend a significant amount of time and money, such as the military domains, the medical industry, and the aircraft industry [16]. In this context

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developed games controlled with BCI have features that can be evaluated both in the serious games category and in the entertainment category.

In this study, a game which provides virtual character control with both Human-Computer Interaction (HCI) and the Brain Computer Interface (BCI) that can be evaluated both in the category of competitive games in the entertainment industry and the serious games in the medical was designed. In this game, the control of the virtual character with HCI was provided by the keyboard hardware. Two different BCI estimation algorithms provided by the "Emotiv Epoc" device were used for BCI control of the virtual character. The performance metrics obtained from the experiments designed with this 2D game, which was developed as two levels with single and multitasking, were compared with each other.

## II. Methodology

In this study; a 2D game design with two levels, including single and multitasking, that provides virtual character control with both HCI and BCI, has been realized. Designed by using a game engine that supports many platforms, two different BCI prediction algorithms have been used in this game. With experiments designed by using the game developed performance metrics were obtained for two different methods, two different estimation algorithms and two different levels. These obtained metrics were compared each other.

In the designed BCI controlled game; Emotiv Epoc + device was used to record the user's brain signals and turn them into commands. This device has 14 channels based on international 10-20 locations, is wireless, and the sampling rate can reach 128 Hz. It is not a medical device as it cannot be used for diagnosis or treatment of diseases. Emotiv device used to control the character of the designed 2D and two-level game with BCI, includes three different machine learning algorithms; performance metrics, facial expressions and mental commands via Xavier ControlPanel software [17, 18, 19]. In the interface developed for the training of algorithms, 8 seconds of training is done for each personal command. Emotiv Xavier Emokey software was used to transfer the trained commands to the virtual character in the game as keystrokes. The purpose of this software is the transmission of brain signals, which are trained for a command, to a virtual character by converting to a specified keystroke. Thus, virtual character control can be performed easily and practically.

The flow chart of the design of the virtual character control system with BCI is given in Figure 1. As seen in the flow chart of the design, the EEG signals obtained by using the Emotiv Epoc + device (01) are processed by transferring to the computer (02) and transformed into the command with the EmoKey software provided by Emotiv (03) and transmitted to the game engine (04), thus enabling virtual character control with brain signals.

### A. BCI Controlled Game Design

2D game design of the system that provides virtual character control with BCI, which has two different levels, was

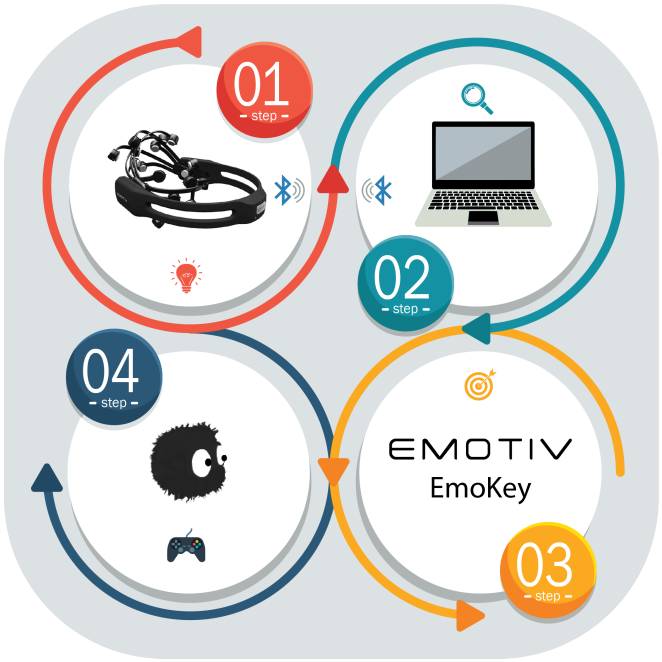



Fig. 1. Flow chart of virtual character control system design with BCI. (01 step) Emotiv Epoc + device from which EEG signals are obtained; (02 steps) the computer where the signals are recorded and processed; (03 steps) EmoKey, which provides communication between Emotiv Epoc + and the game character; (04 steps) game character / game to be controlled by motion.

implemented using the Unity game engine. The first level of the designed game results in the virtual character starting from the start point and reaching the end point. In this first level, there is only one task (command) that needs to be performed. In the second level of the game, there are obstacles that the virtual character must destroy during this journey, so the game has multitasking (commands). This two-level game, designed to be controlled with BCI, has been developed at different difficulty levels in order to evaluate the mental performance of the subject.

The levels of the developed BCI controlled game, It is determined and named based on the tasks that the virtual character will perform. In the first level of the designed game, called "Level 1", the virtual character start from the start point and reach the end point by walking (Figure 2 (a)). The only condition is that the character arrives at the destination. Performance metric is measured by how long the game character reaches the finish point. In the second level of the designed game called "Level 2", the virtual character must start from the start point and reach the end point (Figure 2 (b)). However, in "Level 2", there is a condition that the virtual character destroys the obstacles that arise during journey (Figure 2 (b)). Every obstacle that comes across during the journey can only be removed when it is shooted 3 times at a certain distance.

The tasks that the virtual character must fulfill during their journey are shown in Table I. With the start of the game, it starts advancing and adjusts the range. Then, it shoots 3 times when it sees the target. It continues to move forward.

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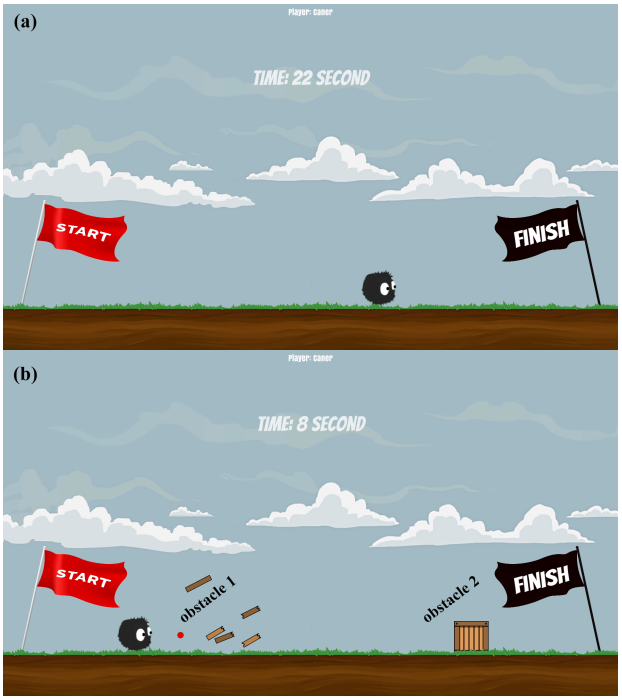



Fig. 2. Levels of the designed 2D game. (a) "Level 1" single task level, (b) Game character shoots and destroys obstacle in "Level 2" multitasking level.

TABLE I
THE LEVELS OF THE BCI CONTROLLED GAME AND THE TASKS OF THE VIRTUAL CHARACTER

| **Game Level** | **Attribute** | **Character's Tasks** | | | |
|---|---|---|---|---|---|
| Level 1 | Conditional single task | Start | Move Forward | Finish | |
| Level 2 | Unconditional multitasking | Start | Move Forward | Get In Range | Shoot |
| | | Shoot | Shoot | Move Forward | Get In Range |
| | | Shoot | Shoot | Shoot | Move Forward |
| | | Finish | | | |

When it reaches the second target, it destroys the target by fulfilling the same conditions and progresses to end the game. The performance metric is measured by how long the game character takes to reach the finish line by shooting and destroying obstacles.

The codes that provides the character control and level flow of the designed game were written in C# using Visual Studio. The control of the virtual character was achieved primarily by using the keys of the computer keyboard, which is the HCI tool. The flow diagram of the software controlling the character is given in Figure 3.

As long as the M key of the keyboard is held down, the virtual character moves towards the end point. Each time the F key of the keyboard is pressed, the character shoots and if the obstacle is at a sufficient distance, it destroys the target as shown in Figure 2 (b). The character needs to shoot three times at obstacles from sufficient distance to destroy targets. The

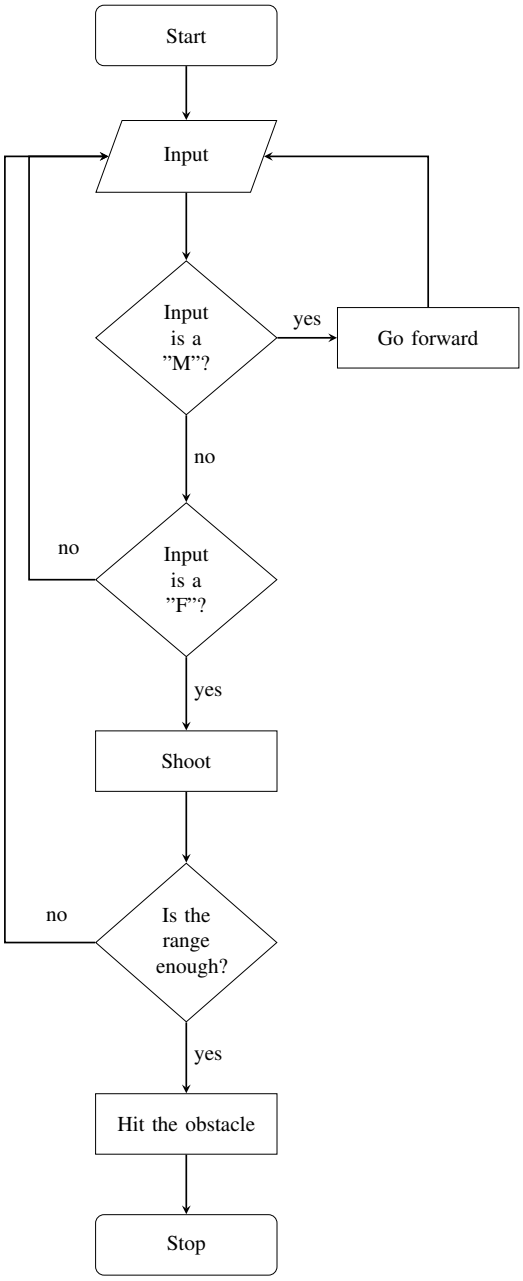



Fig. 3. Flow diagram of the software that provides virtual character control.

time in seconds to be measured for performance comparisons after the game has started. After the game character reaches the finish point, the level ends and the elapsed time is recorded.

To verify the commands of the designed game and the responses of the game character; the application was carried out with a volunteer participant with high game playing experience. During the application, it was observed that the character going forwards when the "M" key is pressed with the keyboard, and the character shoots when the "F" key is pressed. As a result of repeated trials, it was observed that the game character responded properly to the commands sent by the keyboard and performed the expected actions.

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### B. Experiment Design

In this study, applications for 2 different levels were carried out using "facial expressions" and "mental commands" algorithms for character control of the 2D game.

EmoKey software was used to send mental commands and facial expressions (mimic) commands to the virtual character of the game whose design and application rules were explained in the previous section. In the designed game, the M key sent from the keyboard allows the virtual character to move forwards, while the F key allows the virtual character to shoot in order to destroy the encountered obstacle at the appropriate distance. Within the rules written to send a keystroke to the virtual character, the "Smile" and "Clench" facial expression commands were provided to trigger the M and F keystrokes, and "Right" and "Push" mental commands were provided to trigger the M and F keystrokes.

Experimental applications of the developed BCI controlled game were carried out with a healthy volunteer participant with experience in video games and using the Emotiv device. The participant was informed about the rules and levels of the game. Preliminary preparations were made before the participant's facial expressions and mental commands training [20]. First of all, Emotiv device was charged for the healthy start and continuity of the work. Emotiv device was activated by connecting to the computer via bluetooth. The electrodes to be wet and to receive a better signal were hydrated with lens solution and positioned on the participant's head as shown in Figure 4. The quality of the obtained signals was checked via Emotiv Xavier ControlPanel. Device controls were made until a quality signal was obtained.



Fig. 4. Performance study of the virtual character of the BCI controlled game with a volunteer participant.

After the necessary controls were performed, training phase was initiated. In this step, with the virtual object on the mental commands interface, the trainings were repeated until the "training success rate" for the Right (forward) and Push (fire) commands increased. In the facial expressions interface, gestures that the participant can control comfortably were preferred. For mental commands, it has been observed that a strong "Right" signal (greater than 0.2) from the Emotiv Epoc + device sends the M value as a keystroke, and simultaneously moves the character towards the end point. It is also observed that a strong "Push" signal (greater than 0.2) from the device sends the F value as a keystroke, and simultaneously the character shoots. For facial expressions commands, a strong "Smile" signal (greater than 0.2 value) from the Emotiv device sends the M value as a keystroke, and the character moves towards the end point. A strong "Clench" signal from the device sends the F value as a keystroke, and the character has been observed to shoot. The value of 0.2 here indicates that the participant's brain signals action strength is at an acceptable level. In the software, this value is in the range of 0.0 to 1.0.

## III. Results

In the experiments of the game designed to contain two levels with BCI control, which are single command and multiple commands, the subject's mental performance, accuracy-command relationship, accuracy-skill relationship, accuracy-recall relationships were examined. At the same time, the thinking function controlled by the neurons in the brain and the performance metrics created by the facial expressions controlled by the neurons in the brain were also discussed.

In the trainings for mental commands, the skill level obtained in each repetition was recorded. First of all, the command training experience of the participant's game was evaluated, and the results obtained are given in Table II.

TABLE II
THE SKILL LEVELS OF THE MENTAL COMMANDS BASED ON THE REPETITIONS PERFORMED BY THE PARTICIPANT DURING THE COMMAND TRAINING OF THE GAME

| **Repetition** | **Skill Grade** | |
|---|---|---|
| | ***Push (Shoot)*** | ***Right (Move Forward)*** |
| 1 | 0% | 0% |
| 2 | 0% | 14% |
| 3 | 22% | 21% |
| 4 | 50% | 46% |
| 5 | 73% | 79% |
| 6 | 70% | 100% |

Here the "skill grade" is calculated in the training process, thus obtaining a measure of how consistently the user can mentally perform the intended action [21]. When the graphic showing the change of skill levels obtained according to mental commands (Figure 5) is examined, it is seen that the skill level increases depending on the repetitions. The more repetitions the participant does for each command, the more skill level of that command can increase. However, while it can achieve very high accuracy for a single command, the change in accuracy as the number of commands increases is important in terms of evaluating the participant's mental performance and remembering ability. Character control performance metrics were obtained at two different levels of this game designed for this purpose, namely "Level 1" with a single task and "Level 2" with multitasking.

In the experiments performed with the designed game, the participant was provided to play the game with both mental and facial expressions for character control at "Level 1" and "Level 2" levels. In addition, the participant was able to

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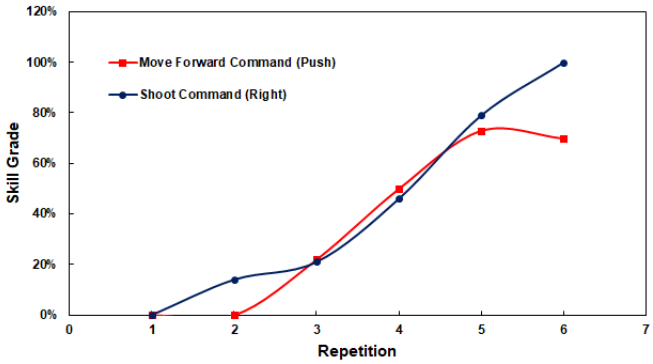



Fig. 5. In mental training for virtual character control in the game developed, depending on the repetitions performed by the participant; change in skill levels of the move forward (Right) and shoot (Push) mental commands.

play the game using the keyboard in order to compare the performance and show the difficulty level of the game. The participant repeated the game 8 times for each level. For two different levels, the scores (in seconds) obtained by the participant starting the game and reaching the end point by controlling the character were recorded. The performances obtained as a result of 8 repetitions at "Level 1" and "Level 2" levels performed with mental commands, facial expressions and keyboard are given in Table III. When Table III is examined for the single task "Level 1" and multitasking "Level 2" levels of the game; the difference between the average time to reach the end point of the character for keyboard and facial expressions is about 2s. For mental commands, it is seen that the difference increases to approximately 15s.

TABLE III
TIME FOR SUCCESSFULLY COMPLETING THE GAME AT LEVEL 1 WITH SINGLE TASK AND LEVEL 2 WITH MULTITASKING (SECONDS)

| Repeat | Level 1 | | | Level 2 | | |
|---|---|---|---|---|---|---|
| | *A* | *B* | *C* | *A* | *B* | *C* |
| 1 | 8 | 47 | 38 | 11 | 41 | 55 |
| 2 | 8 | 37 | 46 | 11 | 45 | 44 |
| 3 | 9 | 44 | 40 | 10 | 41 | 58 |
| 4 | 8 | 43 | 41 | 10 | 38 | 51 |
| 5 | 9 | 38 | 35 | 10 | 44 | 62 |
| 6 | 8 | 37 | 46 | 11 | 36 | 60 |
| 7 | 8 | 34 | 47 | 11 | 39 | 48 |
| 8 | 9 | 35 | 42 | 11 | 47 | 74 |
| **Avg Time (s)** | 8,4 | 39,4 | 41,9 | 10,6 | 41,4 | 56,5 |

[A]Keyboard (s) [B]Face Expressions (s) [C]Mental Command (s)

Change of keyboard and two machine learning algorithm according to the number of repetitions is shown in Figure 6 (a) for "Level 1" with single task and in Figure 6 (b) for "Level 2" with multitasking. It is seen that the performance shown with the keyboard (HCI) is approximately 5 times faster than the performances performed with machine learning algorithms (BCI). Comparing the algorithms of the two machine learning, the facial expressions algorithm provides better performance than mental commands machine learning algorithm in multitasking (Figure 6 (a)).

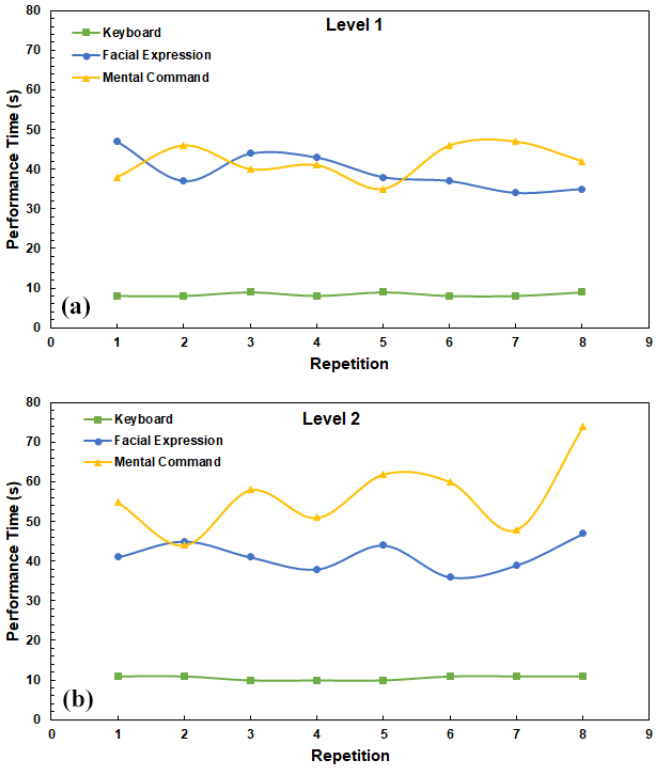



Fig. 6. The time the character reaches the end point for "Level 1" (a) and "Level 2" (b), which contain a single task according to the methods used.

The variation of each method applied in the control of the designed game character at "Level 1" with single task and "Level 2" with multitasking can be examined. In Figure 7 (a), performance times according to the number of repetitions can be seen in "Level 1" with single task and "Level 2" with multitasking, where the participant provides character control using the keyboard. When the performance times of both levels are compared, there is approximately 2s difference between the time to reach the end point of the character in the two games. When both curves are considered, it is seen that the change of the curve is almost constant, and there is no change in performance. In Figure 7 (b),it is seen that the time to reach the end point of the character according to the number of repetitions for "Level 1" and "Level 2", where character control is provided using facial expressions. Again, as with the keyboard, the difference between performance times at both levels is around 2s. Therefore, between "Level 1" and "Level 2" levels of the game, it can be evaluated that the performance times of both methods are almost the same, the difficulty level of the game is the same during the game control with the keyboard control and facial expressions. However, when examined for "Level 1" and "Level 2", the difference between performance times in which character control is achieved by using the mental commands given in Figure 7 (c) is around

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15s. This means that the difficulty of level of the game (when comparing Level 1 and Level 2) increases when it comes to mental commands.

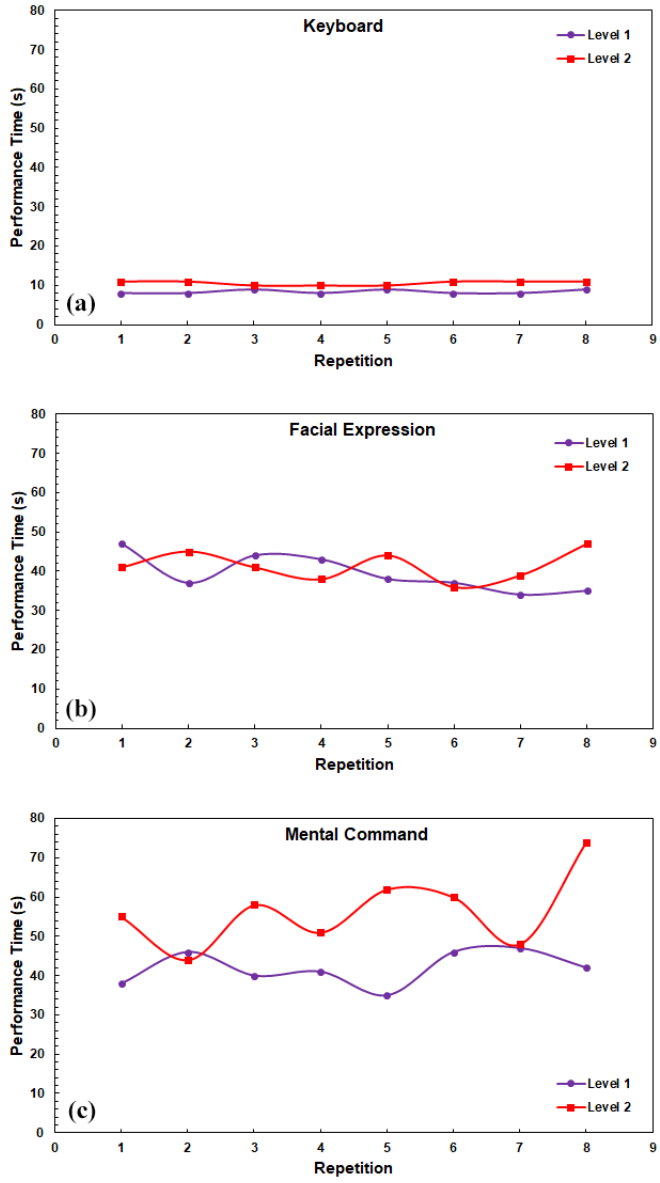



Fig. 7. The arrival time of the character to the end point according to the number of repetitions for "Level 1" and "Level 2" provided character control using keyboard (a), facial expressions (b), mental commands (c).

The fact that Level 2 is considered more difficult when mental commands are applied. It can be explained by multitasking. The difficulty of the levels (performance times) between the levels of the designed game are much higher when mental commands are used compared to the other two methods (15s $>$ 2s); it can be evaluated as an indicator of the mental performance of the subject in multitasking. While mental commands can achieve very high accuracy for a single command in the machine learning algorithm, the accuracy decreases as the number of commands increases. In this case, the accuracy also depends on the skill level of the user and the ability to remember the mental state used in training. In the facial expressions machine learning algorithm, since there is no ability to remember the mental state, the facial expressions machine learning algorithm at the multitasking level gives better results.

During these experiments, it was observed that the subject leaves a scar on the scalp due to the long-term use of the Emotiv device, which is used to record brain signals. Also participant; stated that after intense experiments, he was dizzy and nauseous. The emergence of these findings can be interpreted as the participant performing the experiments by providing intense concentration or as the coincidence of the electrodes (sensors) positioned on the scalp with the acupuncture points.

## IV. Discussion

In this study; virtual character control experiments were carried out with the BCI controlled game developed as a platform to examine the timing and dynamics of brain control. In this designed system; facial expressions and mental commands provided by the Emotiv device used were compared with machine learning algorithms. In the experiments of the game designed to contain two levels with BCI control, which are one command and multiple commands; the subject's mental performance, accuracy-command relationship, accuracy-skill relationship, accuracy-recall relationships were examined. Comparative results of performance metrics obtained by these two different machine learning algorithms are predicted that these results can contribute to future research of mental states during real-time tasks and decision-making processes.

When the results obtained in this study are evaluated; transformation of brain activities into meaningful commands by making of the sense and the estimation as allowing a fluent game with BCI, is temporal delayed compared to HCI. Some games need up to 8 seconds to fully translate a brain signal into a command, not taking into consideration the chance of misunderstanding the user's intention caused by natural error rates [9]. Games using consumer grade EEG devices are particularly prone to this problem as they use fewer sensors hence have a smaller spatial resolution. Due to this delay, it is an important problem that the games developed with mental commands are not preferred by the players. In this context, game platforms can be developed that take this limitation [6] into account and allow interactive game design with consumer grade EEG devices.

Also, the effects of graphical user interfaces and sounds and animations used in games on players should be taken into account in BCI-based game design [22]. These effects can distract the player and affect the accuracy of the BCI system negatively, especially in games that require mental commands. Thus, the player may lose interest quickly in playing with BCI.

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