Cognitive Training Programs with EEG Headset

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Abstract

In order to improve cognitive skills, we developed a series of training programs using the Unity 3D™ Game Engine through the EPOC headset with the EEG technique from EMOTIV™. To keep participants' interest and improve training efficiency, each program was developed as a game-like application with three levels of difficulty. The programs allow users to play games according to the game rules. Our programs focus on such cognitive abilities as reaction speed, flexibility, attention span, memory and problem solving. The detection system is able to analyze the user's training performance, thus automatically channeling the user to a suitable training level. A preliminary testing was conducted for a short term, and the result was positive. This pilot study is used as proof of principles and serves as a basis for developing more comprehensive cognitive training programs in the future.

Introduction

Cognitive training programs generally involve a series of interactive computer-based exercises that are designed to improve trainee's mental abilities such as knowledge acquisition, attention, memory, judgment and evaluation, reasoning, problem solving and decision making, comprehension, and production of language. For a period of time, cognitive capacity was believed to be fixed after a brief critical period of early development [1-6]. In this view, little could be done to improve cognitive skills during adulthood. However, recent research has shown that cognitive capacity, rather than being fixed and non-improvable after

the early stage of development, can be continually improved in efficiency and effectiveness when exposed to proper practices [1-9]. Cognitive training has been shown to be effective in a variety of populations. Many such programs, however, are aimed at older people and especially individuals with mental problems such as Alzheimer's disease. Little has been done on normal and healthy college students [1]. Furthermore, the existing literature on cognitive training only focuses on software development. There is no real-time feedback from the trainee's brain showing the practice performance in order to adjust training exercise levels.

As a pilot project, we developed interactive software programs for cognitive skills training by connecting with the electroencephalogram (EEG) hardware (EMOTIV™). In this system, the EEG hardware is not only used for recording the brainwaves, but its recorded data also serves as an input in the training program for level adjustment and performance analysis. In this way, the program can be adjusted and customized dynamically according to the participant's level of cognitive skills.

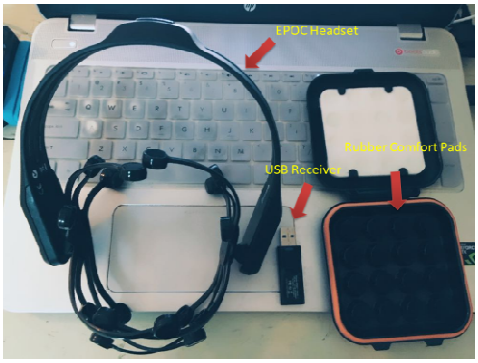
We incorporated the game design into all training programs by connecting a headset to receive and process the raw EEG data. The headset from EMOTIV™ is used as the brain-computer interface based on the EEG technology. The programs are capable of detecting the user's mental commands, performance metrics, emotional states and facial expressions in real-time. The input of the detected signals is used to monitor the user's state of mind so that the difficulty level of the program may be tailored and adjusted to suit each situation. The game-like training programs were developed to attract participants in the general population, especially college students. With more and thorough feedbacks, program will be improved accordingly, thereby achieving the training goals more efficiently.

Another benefit of using such a convenient, easy-to-use program is that it requires no direct one-on-one consultation [1-6]. This type of instructor-free system should be welcomed by a wide variety of audiences. When perfected, it shall be useful for improving performances on many critical tasks of everyday life in a world of ever-increasing cognitive demands.

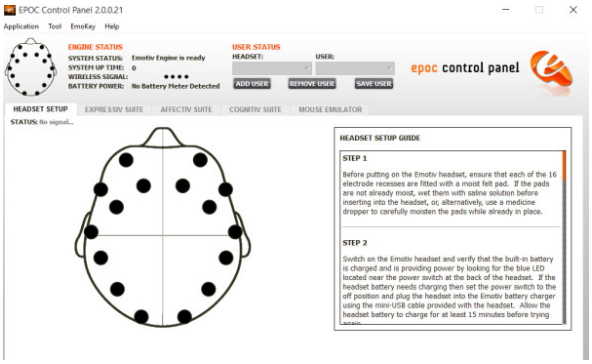
Approach

The Emotive EPOC headset was used as a brain–computer interface based on the EEG technology [11]. Unity3D was applied to develop the interactive computer programs.

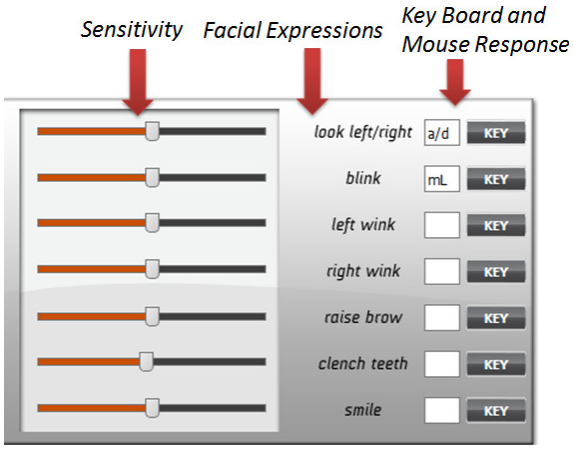
The initial setup for the headset is to utilize certain EEG data as the input of the training programs [11]. The setup of the headset is to render the availability of three detection suites: Facial Expressions (Expressive), Emotional States (Affective), and Mental Commands (Cognitive). All three detection signals can be used to connect with Emo Key component implemented in EPOC Control Panel and will automatically convert into keyboard and mouse responses with user's presetting (Figure 1). More features of EPOC can be activated using the Control Panel software, including the use of an inbuilt gyro as a mouse emulator and the mapping Emo Key to keystrokes on the keyboard [11].



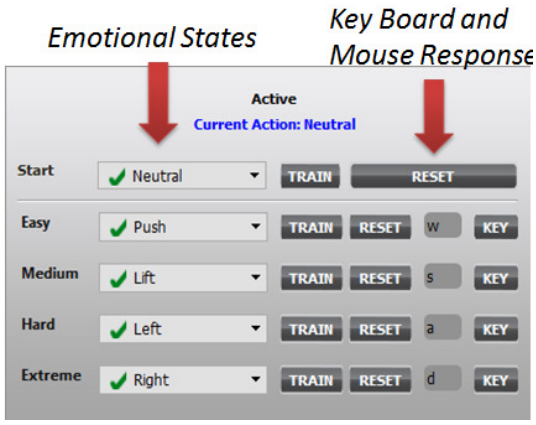
(a) EPOC Headset and Accessories



(b) EPOC Control Panel



(c) Facial Expressions Control



(d) Emotional States Control

Figure 1. EPOC Technology

Almost all teenagers and students play games and apps with their phones and computers nowadays. Therefore, we attempted to develop our training programs by incorporating some popular game designs for mental improvement.

A. Reaction Speed Training Game

The training program "Faby's Dream" was designed for training the attention and response speed by directing a flying bird to avoid random obstacles (Figure 2) [11].

Game Rules: The user is required to direct a flying bird, which moves continuously to the right between sets of Mario-like pipes. At the same time, gravity is applied on the bird. If the bird collides with any pipe, the game is over. On the other hand, if the user leaves the bird alone, the bird falls to the ground due to gravity and the game is over. Higher speed represents higher level, and the level will be increased with time going on. Through the headset, we incorporated the user's facial expressions as the input to the program to flap the bird either up or down to avoid the obstacles.

The score system is to calculate the number of points the user makes in each game. One point is awarded for navigating the bird through each pair of pipes. If the user earns high points at the end, a medal is awarded and the program is changed to the next suitable level of difficulty with more pipes and a faster flying speed.

Figure 2. Graphic Structure of Flappy Bird

B. Attention Span Training Game

Based on the game of "Don't Tap the White Tiles", we developed a program called "Colorful Blocks" (Figure 3) [12]. The program was designed to improve memory and response speed.

Game rules: The user must tap on the colorful tiles as they appear from the top of the screen, while avoiding the white. Higher speed represents higher level, and the level will be increased with time going on. If the user taps on a white tile, an off-tune note is signaled and the game is over.

The score system records the scores only by tapping tiles with colors. Three points are awarded for each of the bright colored tiles (red, yellow, orange, green, blue, and purple), and two points for each of the grey tiles. The game ends when a white tile is clicked. If the user earns high points within a limited time, the program is changed to the next suitable level of difficulty with more tiles on the screen.

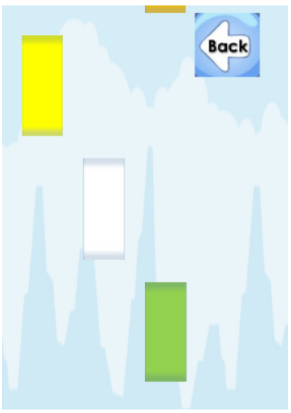


Figure 3. Color Panel for Colorful Blocks

C. Memory Training Game

Our training program "Card Match" was designed to train the user's memory and response speed within a certain time limit (Figure 4). The user is required to eliminate all blocks by matching a pair.

Game Rules: In the game, each card has a random color assigned and only the back of the card is shown to the user. The user is allowed to flip two cards at the same time. If the two cards have the same color, both of them will be eliminated from the program. The user is required to eliminate all blocks in a certain time. The matrix of cards will be increased automatically if the user completes the task at the lower level within a certain time. The score system is set to record the final card numbers successfully matched by the user and the time spent to achieve that level. If the user earns high points within a limited time, the program is changed to the next suitable level of difficulty with more cards on the screen.

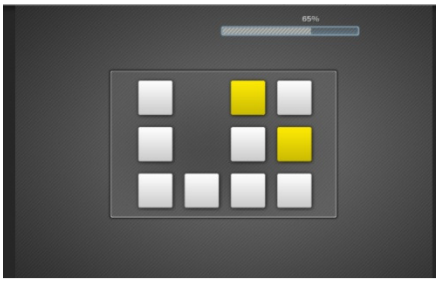


Figure 4. Card Match

D. Problem Solving Training Game

The idea of this training program was borrowed from the Chinese chess-like game known as "Go" [13]. Based on the same principle, our program "Surrounding Game" was designed to improve problem solving capability (Figure 5).

Game Rules: The user needs to figure out a way to set up a complete barrier surrounding the "smart cat" to prevent it from running (escaping) into the edge of scene. At the beginning of the game, there are only a few barrier blocks distributed randomly on the scene and the user is to add more such blocks to completely surround the "smart cat." On the other hand, we designed an intelligent strategy for the "smart cat" to escape cleverly through one of six directions. This included both the shortest path algorithm and the maxima algorithm. The former is to help determine the shortest path to escape to the edge, and the latter to determine the steps when the "smart cat" was blocked. The score system records both the steps to surround the "smart cat" and the total amount of time needed for the user to win the game (totally blocking the smart cat). When the "smart cat" runs to the edge of scene, the game is over. The more difficult level of the game includes more barrier blocks.

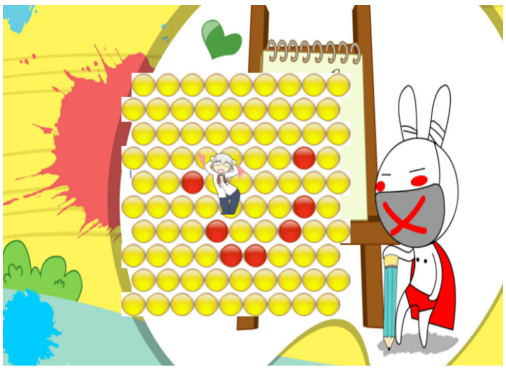
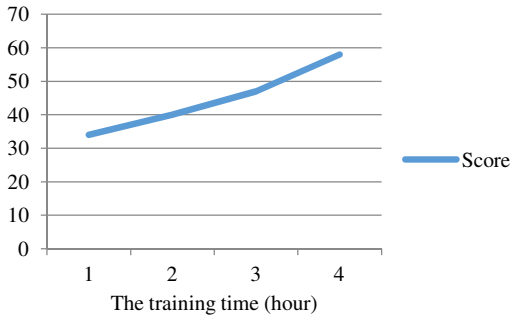


Figure 5. Screen snapshot of "Surrounding Game"

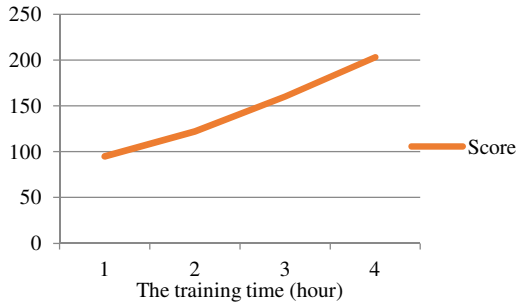
Training and Analyzing

A preliminary testing was conducted for each training program for a short term. We picked three users for each game (two males and one female student, ages 20-24). Each user was trained with the training programs under four categories of memory, attention span, response speed and problem solving for sixteen hours in total. The scoring system in each game recorded the response speed, number of cards correctly clicked, cards memorized within a limited time, and the time to successfully block "smart cat" escaping from the barrier blocks correspondingly.

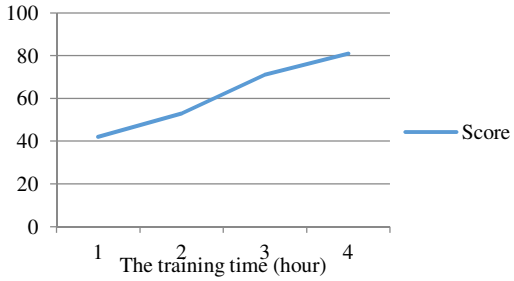
The average training results from the three users are summarized in Figure 6. Each training session lasted about four hours, with the highest score from each training session used in the figure.



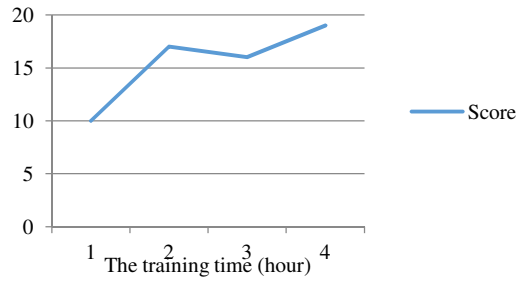
(a) "Faby's Dream" training results



(b) "Don't Tap the White Tiles" training results



(c) "Card Match" training results



(d) "Surrounding Game" training results

Figure 6. Average training results

From the above results, we can see that training for reaction speed, attention span and memory were all improved. There is no apparent linear improvement in the training for problem solving ability. As the training time growth, games level increased, and higher score will be recorded. While we cannot definitely conclude that the training is effective for improving the first three aspects either, we have not analyzed if the improved results are due to the training itself or caused by the more familiarity with the training programs. More games used to balance people's familiarity and games' effect will be designed and further testing and analyses involving more participants will be conducted in the future.

Conclusion and Future Work

The cognitive training programs were developed to improve specific mental abilities and processes. The significance of these programs includes the incorporation of game design ideas and the use of real-time signals from a headset. The headset from Emotive serves as the brain-computer interfaces based on the EEG technology. The programs are capable of detecting users' facial expressions and performance metrics in real-time. The detected signals are read as the input to the training programs, so that the user's state of mind can be monitored in real-time and the level of the game can be tailored to suit each case. The game-based training programs are selected to attract participants, especially younger ones. With

more and thorough feedbacks, program will be improved accordingly, thereby achieving the training goals more efficiently.

The present study is a pilot project. In the future, more headsets will be used to develop networking programs for more competitive training. Testing on more features, such as reaction speed, flexibility, attention span, memory and problem solving ability, will be included to help improve the training programming. More comprehensive testing, including comparison with traditional means of testing and improving the markers (Memory, etc.), will also be conducted.

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