The Design and Development of Empathetic Serious Games for Dyslexia: BCI Arabic Phonological Processing Training Systems

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Abstract. In this paper, we describe the User Interface (UI) design issues for serious games aimed at developing phonological processing skills of people with specific learning difficulties such as dyslexia. These games are designed with Brain-Computer Interfaces (BCI) which take the compelling and creative aspects of traditional computer games designed for Arabic interfaces and apply them for cognitive skills' development purposes. Immersion and engagement in the games are sought with novel interaction methods; the interaction mode for these games involved mind-control coupled with cursor-based selection. We describe the conceptual design of these serious games and an overview of the BCI software development framework.

Keywords: Brain-Machine Interface, BMI, SpLD, Learning Difficulty, Dyslexia, Brain-Computer Interface, BCI, Usability.

1 Introduction

Serious games have received increasing interest in Human- Computer Interaction (HCI) research [1,2]. Correspondingly, many accessibility researchers have taken up the challenge of establishing how to best design rehabilitation software and remedial software training programs for developing skills of people with cognitive disabilities and learning difficulties [2]. The development of serious games aimed at language processing skills in particular could contribute to the proliferation of immersive and engaging learning experiences for people with learning difficulties such as dyslexia.

Recent studies have shown compelling evidence in how traditional computer games enhance the learning experience [2]. Gamification in rehabilitation software for auditory processing difficulties and specific learning difficulties has been shown to be

A. Marcus (Ed.): DUXU 2014, Part IV, LNCS 8520, pp. 105–112, 2014.

effective with users across of the spectrum of difficulty levels [12, 13]. Exploiting existing novel interaction methods, such as mind-control and adaptation via affective computing, can impact the user experience in serious games by increasing levels of immersion and engagement [3, 5]. These user experiences have the potential to enhance the motivation, maintain the momentum of learning, and assist educators and practitioners in objectively monitoring the progress of the individuals as well as assessing the effectiveness of configurable remedial programs in these serious games [5, 8]. The concept of such emerging technologies, such as Brain Computer Interfaces (BCI) is leveraging the engaging aspect of using brainwaves, to control elements in an immersive environment, to enhance the learning experience [4, 5].

2 Brain-Computer Interaction in Serious Gaming

BCI research is a growing domain of interest for the design and development of assistive technologies, gaming, and applied contexts of affective computing. Much of the prior research in BCI for assistive technologies is aimed at individuals who have physical disabilities that hinder their ability to manipulate tangible controls (e.g. paralysis), attention deficit disorders (e.g. ADD, APD, and ADHD), and developmental disorders. The gaming paradigm is an interesting platform to employ BCI to further assist the aforementioned target user populations through the translation of user's mental activity into game controls and increasing engagement with nocel interaction modalities for the purpose of immersion in learning activities and improved accessibility.

In recent years, games are increasingly being designed with novel multimodal interaction [8, 10]. BCI games in this domain have leveraged the capability of detecting attention to develop the cognitive skills of players such as sustaining attention [10-11]. Studies examining the usability and user experience (UX) of BCI games have suggested increased levels of engagement and immersion in BCI games [14, 15]. However, the inaccuracy and complexity in controlling objects within the games have been noted as challenges for gamers [16]; these difficulties often hinder their ability to progress within the games and demand higher learning curves when compared to traditional modes of interaction.

3 Mind-Controlled Dyslexia Training

An application for cognitive training of phonological processing skills for Arabic-speaking children with SpLDs was developed. The serious game was designed for the Emotiv EPOC headset to detect patterns of brainwaves for controlling the selection mode in the game and to detect levels of basic affective states (e.g. frustration, excitement, boredom), with frustration levels being linked to controls within the game. The two channels of interaction are depicted in the model illustrated in Figure 1.

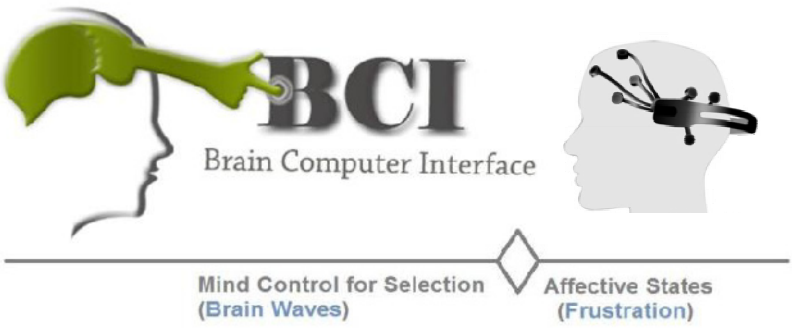

Fig. 1. BCI game based on brainwaves for selection and affective states for adaptation

The electrical activity in the brain can be monitored using different ways. One of these methods is non-invasive; it involves detecting the signals from the human scalp without any surgical intervention. Electroencephalography (EEG) technology is a well-known method used to record brain signals in a non-invasive way.

Several companies have released devices For EEG brain computer interface (BCI). One of these devices is EPOC, it is produced by Emotiv Systems. EPOC is a headset that contains 16 sensors distributed over different areas on the brain to detect EEG signals [6]. This headset not only provides the capability to measure cognitive and expressive emotions, but it also provides a mechanism of detecting facial expressions [7]. The interaction modalities made available with the EPOC headset as well as its unobtrusive properties as an input modality have made it an attractive tool to consider in this project. In the following sections, we describe the design framework that guided the development of the BCI serious games.

3.1 Developing the Interaction Modalities for the BCI Application

To work with EPOC headsets, a bespoke application was developed using the Educational Emotiv Software Development Kit (SDK) which is a "toolset that allows development of applications and games to interact with Emotiv EmoEngine and Emotiv neuroheadsets" [6]. There are several components in the SDK that are essential for the design and development of BCI applications. The Control Panel provides an interface to detect the locations of the headset sensors and to train the EPOC on each user [6]. The EmoComposer is an emulator of EmoEngine which can be used without the headset. The Emotiv EmoEngine refers to the logical abstraction of the functionality that Emotiv provides and it streamlines the flow of data to the Emotiv headset as it "receives preprocessed EEG and gyroscope data, manages user-specific or application-specific settings, performs post- processing, and translates the Emotiv detection results into an easy-to-use structure called an EmoState" [6].

3.2 Software Architecture and Design of the BCI Application

In the development phase of the application C# was selected for the programming language and the composer was used to emulate interaction in iterative design cycles to facilitate rapid development and testing in a context with limited access to headsets for each member on the development team. When a user starts the game, a direct connection to the EmoEngine is established using the calling function of engine.Connect(); after the user logs in and before the user starts playing, functions are called for the different processes:

1. User Profile: This function checks whether the user has a previously existing profile. If the user is not new to the system, or a profile is found, then the user's training data is retrieved.
2. User training data: If the user is new, then the EPOC headset must be trained to understand the cognitive data for that specific user before moving on to the game. The training data often involves the individual's pattern of imagining an action such as push, pull or navigation directions. In our case, we were interested in the push signal only, so training was designed to be conducted for that specific signal.
3. Measure the frustration, boredom, and excitement: The Epoch headset detects affective states of an individual such as levels of frustration, boredom, excitement and meditative states. After retrieving the training data, the user may start the game. In each stage of the game, the EPOC headset will detect the frustration level of the user. When the serious games detect high levels of frustration for the player, the system automatically adapts by reducing the complexity of the game, such as the scenario depicted in Figure 4.
4. Push: After proper training, the EPOC headset should be able to recognize the push signal immediately. So, when the user thinks of pushing a button in the game, the push signal will be detected and matched with the signal learned during training. Thus, the button in the game was designed to trigger the action being detected by the neuroheadset and reflect the system's response.

3.3 Flow of Cognitive Training in the BCI Game Scenarios

The serious games developed in this project aim to develop the key skill of auditory language comprehension in Arabic-speaking individuals with developmental dyslexia. Phonological processing impairments are often experienced in people with dyslexia and these can be addressed in drill based exercises that aim to develop the skill in auditory and visual stimuli [7]. The use of serious games in rehabilitation and cognitive training programs has been considered by researchers and practitioners to optimize the rehabilitation of learning disabilities [10-11]. In addition, the innovative approach of BCI interaction that is considered in these games has been shown to provide the user with an enhanced user experience (UX) of motivation and enjoyment and better engagement levels in the gaming experience [14-16].

The BCI game was designed as a self-training tool that aims to improve the phonological language skills of people with developmental phonological dyslexia; their inability to map printed words onto their corresponding sounds of spoken words reinforces the need for a proper treatment, given that this language difficulty affects their reading and spelling skills [9].

In this BCI gaming application, the user is required to wear the neuroheadset while playing the game to detect subconscious emotional states and user-trained mental commands for proper control of objects presented within the game. The two channels of interaction we have chosen to be detected for this game are the “push” action and frustration levels, these are depicted in the model illustrated in Figure 1. A sample of the game's interface is shown in Figure 2; in which users listen to a spoken Arabic word by the program. Following the auditory trigger, users are expected to navigate the cursor to the correct word and then concentrate to make their selection.

Fig. 2. Mind-Controlled Selection of Words

The game consists of three different levels each containing five stages. The complexity and challenge of the game relies on the number and the weights of the presented words; the similarity between the weights of different Arabic words makes it more difficult for the dyslexic player to distinguish between their pronunciations correspondences. The difficulty of the game increases as the player proceeds to the following levels.

Figure 3 shows a sample of the three different levels. Level one presents three words with different weights as depicted in Figure (3.1). Level two presents five words (three words with the same weight (3.2), and level three presents seven words (five words with the same weight) as depicted in Figure (3.3).

At the beginning of each stage, the player will listen to the pronunciation of a word generated by the program and try to match it with its corresponding text. To choose an answer, the user is expected to move the cursor to the correct word and concentrate on it to trigger the push action from the headset. The games' ability to recognize human emotional states with physiological signals facilitated the design of an empathetic system in this learning contexts and thus maintaining the engagement level throughout the interaction in the games. For example, selection of the word is made by focusing the user's cognitive attention on the item of interest for a duration that is above the threshold which is configurable by the system administrator.

Fig. 3. Varying levels of difficulty in the game

The headset also detects affective and meditational states. The affective state relevant to the design of this specific game was 'frustration'; frustration levels of the player while interacting with the game. The result of this detection could help in reducing the anxiety experienced by the user when facing difficulties in choosing the correct answer. As higher levels of frustration are detected, the program responds by reducing the answer choices and eliminating one of the incorrect answers to adapt the level of difficulty in the game. Levels of difficulty are configurable by the administrator of the system and can be designed to adapt to users with SpLDs who have varying levels of abilities. One scenario of adaptation in response to affective states of the gamers is depicted in Figure 4.

Fig. 4. Empathetic Design Responding to the Gamer's Frustration Level by Systematically Reducing Complexity

The game was designed so that gamers would be required to answer at least 80% of the questions correctly in order to proceed to the next level. The number of incorrect attempts for each stage will be recorded to decide on the result that will be displayed at the end of each level. Furthermore, the time taken for each player to choose the correct answer will be recorded to test the performance and speed of phonological processing. Both the level of disability (mild, moderate or severe) and age will be taken into consideration for each user to further classify our results from this study.

The chosen words for the game were collected from previous projects that are targeted for users' with learning disabilities and were carefully studied and revised by specialists [12,13].

4 Conclusion

In this paper we described the design and development of a mind-controlled serious game for dyslexia. Despite the emerging BCI gaming field, there are few design frameworks that facilitate integrating emotion recognition and mind-control effectively by developers of rehabilitation software. The work reported here offers a first step towards addressing the inadequate understanding of how BCI can be utilized in configurable applications for specific learning difficulties. Future work involves usability evaluations of the application with users of varying levels of difficulties.

Acknowledgement. The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding the work through the research group project number RGP-VPP-157.

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