Entertainment Computing 5 (2014) 391–399

Contents lists available at ScienceDirect

Entertainment Computing

journal homepage: ees.elsevier.com/entcom

Comparing interaction techniques for serious games through brain–computer interfaces: A user perception evaluation study ☆

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ARTICLE INFO

Article history:
Received 11 April 2014
Revised 25 September 2014
Accepted 10 October 2014
Available online 22 October 2014

Keywords:
Serious games
Brain–computer interfaces
Virtual environments
Human–machine interaction

ABSTRACT

This paper examines the application of commercial and non-invasive electroencephalography (EEG)-based brain–computer (BCIs) interfaces with serious games. Two different EEG-based BCI devices were used to fully control the same serious game. The first device (NeuroSky MindSet) uses only a single dry electrode and requires no calibration. The second device (Emotiv EPOC) uses 14 wet sensors requiring additional training of a classifier. User testing was performed on both devices with sixty-two participants measuring the player experience as well as key aspects of serious games, primarily learnability, satisfaction, performance and effort. Recorded feedback indicates that the current state of BCIs can be used in the future as alternative game interfaces after familiarisation and in some cases calibration. Comparative analysis showed significant differences between the two devices. The first device provides more satisfaction to the players whereas the second device is more effective in terms of adaptation and interaction with the serious game.

1. Introduction

The past decade has seen a huge proliferation of commercial interaction devices for video games. Each of these new devices offers a diverse way of interacting with games and computer generated simulations. Typical technologies that these devices use include: optical, auditory, magnetic and inertia sensors. Some can operate as autonomous controllers while others work in hybrid mode (with standard I/O devices such as mouse and keyboard). However, only the hybrid approaches appear to be functional, the rest require a lot of physical effort. This restricts users' expressive capabilities as well as the information transferred from the user to the computer [1]. Nowadays, non-invasive brain–computer interfaces (BCIs) are getting a lot of attention as alternative human–computer interaction devices for games and virtual environments [2,3].

Non-invasive BCIs operate by recording the brain activity from the scalp with Electroencephalography (EEG) sensors attached to the head on an electrode cap or headset without being surgically implanted. However, they still have a number of problems and they cannot function as accurately as other natural user interfaces (NUIs) and traditional input devices such as the standard keyboard and mouse [4]. The Information Transfer Rate (ITR) of this kind of BCIs is still around 25 bits per minute [5], which makes them much slower compared to traditional input devices such as keyboard (which have typical speed of over 300 characters per minute, roughly 400 bits per minute) [6]. The main reasons behind this are due to bad classification, long training procedures, latency issues and cumbersome hardware [7]. Also, because of lack of training and accessibility in using BCI devices, some people find it difficult to use at all [8].

The majority of BCI studies are performed in laboratory environments under controlled conditions. However this is not always possible in real-life applications and makes current BCI technology not quite suitable for practical applications and widespread use [9]. Game designers and researchers must make sure that BCIs used for gaming environments should not become a barrier in terms of the interaction [10] but on the contrary a more effective medium. Although non-invasive BCI technologies seem to have the potential of providing an environment where "thoughts are not constrained

☆ This paper has been recommended for acceptance by Christos Gatzidis, Ph.D.

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http://dx.doi.org/10.1016/j.entcom.2014.10.004
1875-9521/

by what is physically possible" [7], they are still not ready for commercial use.

The main aim of the paper is to examine the effectiveness of two different BCI devices for fully controlling an avatar inside a serious game. The objectives of the paper are threefold. Firstly, to enable a user to fully control an avatar in real-time using only EEG data. Secondly, to qualitatively examine the behaviour and different reactions of the users while playing the game and, thirdly, to test each device in terms of: learnability of the interface using the game, satisfaction of the player, performance of the interfaces and effort expended by the player. Two different EEG-based BCI devices were used; one which requires no calibration (NeuroSky MindSet) and another one that requires the training of the classifiers (Emotiv EPOC). The user is visually stimulated by fully controlling an avatar in the serious game (see Section 3). Two different types of EEG-based BCIs were used: the NeuroSky MindSet and the Emotiv EPOC. All tests ($N = 62$) were conducted using the same serious game, which was integrated with the devices; participants were divided equally across the devices.

The rest of the paper is structured as follows. Section 2 provides background information for serious games and BCIs. Section 3, presents the serious game that was used as a case study called Roma Nova. Section 4 demonstrates how the two different BCI devices were used for controlling the same serious game. Finally, Section 5 presents the evaluation results and Section 6 the conclusions and future work.

2. Background

Early non-invasive BCI research methods for serious games interaction were usually oriented towards the medical domain rather than entertainment. This kind of research was targeting locked-in patients where haptic and linguistic interfaces fail. The first BCI game was created in 1977. In this game, the user could move in four directions in a maze by fixating on one of four diamond-shaped points periodically flashed. The methodology used was far ahead of its time using online artefact rejection and adaptive classification. The information transfer rate (ITR) was remarkable even for today's standards being above 170 bits/min [11].

Two survey papers regarding BCI systems have been recently published [12,13]. In another recent paper the opportunities and challenges posed by neuroscientific methods when capturing user feedback and using the data to create greater user adaptivity in game are explored [35]. Berta et al. [36] provides an electroencephalogram and physiological signal analysis for assessing flow in games. The paper defines flow in games as a measure of keeping the player fully immersed and engaged in the process of activity within the game. The evaluation of flow involves a 4 electrode EEG, using the low beta frequency bands for discriminating among gaming conditions. Using simple signals from the peripheral nervous system three levels of user states were branded using a Support Vector Machine classifier. The user states where identified using 3 levels of a simple plane battle game identifying states of boredom, flow and anxiety. The paper argues that a personalised system could be implemented in a consumer context allowing for more flowing gameplay in consumer games.

Moreover, there are a number of experimental applications of using BCIs with computer games. Some of these prototypes are very simplistic and just allow the users to select 3D objects in games based on their attention levels [9]. Nowadays, many different techniques are currently used in BCI systems for user interaction and control. Steady State Visual Evoked Potentials (SSVEP) using flashing lights for visual stimulation, the P300 BCI is measuring the brain evoked response after stimulus onset with a positive curve on the EEG after 300 ms and the ERS/ERD which stands for event related synchronisation/desynchronisation through the imaginary limp movement.

An example of BCI-based input devices using motor-control is the mu (μ) rhythm based first person shooter game proposed by Pineda et al. [14] which uses information from the motor cortices of the brain to steer left/right, while forward/backwards movement is controlled by physical buttons. Another similar BCI system by Krepki [15] uses motor-control based on lateralized readiness potential (LRP) – a slow negative shift in the EEG over the activated motor cortex – for controlling the Pacman game. An example of P300 based games are Bayliss virtual driving task and a virtual apartment [16], [17] with highlighted red objects evoking a P300 when the user wants to make a selection.

Another recent P300 game is Finkes MindGame [18] were the P300 events are translated into movements of a character on a three-dimensional game board. SSVEP based games have been also designed based on subjects' attention to a visual stimulus. In the Mind Balance game [19], a SSVEP is evoked by two different checkerboards with the participant's attention focused in one of the two checkerboards to balance an avatar on a piece of string. An advantage of SSVEP over induced BCI paradigms is the multiple option selection by focusing attention on a stimulus. An example is the 2D racing game using SSVEP to control four different directional movements [20] in a similar way to how the FPS game was controlled in SSVEP BCI [21].

There are a lot of prototypes that use a multimodal approach by combining BCIs with other gaming controllers (i.e. keyboard, mouse, Wii controller, etc) [7]. A typical example of multimodal BCI system is the Bacteria Hunt game where the goal is of 'eating' as many bacteria as possible [22]. The user avatar is controlled using the keyboard whereas the amoeba is modulated by the user's alpha activity (higher alpha results in more control). In the game 'FindingStar', users control the entities of the game using emotional signals coming from the BCI and use the mouse and the keyboard to defeat monsters and solve puzzles [23]. The 'NeuroWander' game uses the emotional and attentional states of the users to perform various quests and the navigation is performed using mouse and keyboard [24].

'Affective Pacman' was developed to investigate the frustration of users while playing a BCI game [25]. The game is controlled with two buttons that rotate Pacman. Frustration is caused by malfunctioning controls of the game. In another study, a steady-state visual evoked potential (SSVEP) based BCI, was used to control an avatar in the game 'World of Warcraft' [26]. To control the avatar, users had to control four icons. Three were used to have the avatar turn left, turn right and move forward and an-other one to perform certain actions such as grasping objects and attacking other objects.

In another study, researchers used BCI technology to interact with mobile games [10]. A maze game with three different levels utilising meditative and attentive states was tested with 22 participants. Results indicated that the use of BCI technology with mobile games has the potential to offer new and exciting ways of game interaction. The MindFlex game is a commercial EEG-based BCI game played as a social activity at home [27]. The aim of the game is to interact with a floating ball around an obstacle course assembled on the game board. While these kinds of BCI techniques for controlling games are quite interesting, most of the games so far are proofs of concept. The interaction with these games is really slow, often with decreased game-play speed to allow for BCI control. This has an obvious impact on the average gamer, resulting in potential frustration and loss of engagement and interest.

3. The Roma Nova serious game

The aim of the Rome Reborn project was to create highly realistic 3D representations illustrating the urban development of