Affective Play with a Recycling Serious Game - A Physiological Study

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***Abstract* — the potentials of computer games for developing 'edutainment' (education by entertainment) content and services have been widely explored by researchers in recent years. In order to complement existing presentations and create a memorable enjoyable learning experience, computer games are used in current educational practices. They offer educators opportunities to reorganize and conceptualize abstract, complex and technological information or knowledge for young learners. To demonstrate and evaluate how a serious game can facilitate the learning activities in a more constructive and meaningful way, we select a computer game which is about the waste recycling to conduct a user study and investigate the pedagogical effects of this game. While designing this user study, we particularly focus on the link between game play and physiological state of a player as the measurement of his performance. Both quantitative and qualitative data are collected during the study. The results have shown that this game indeed can help learners understand the important knowledge of waste recycling being studied. The study also indicates that physiological signals can be an indicator of his mental state of a player to some extent. Further direction will be adding other physiological measurements like heart rate and etc during a user study..**

Keywords - waste recycling, physiological signals, game based learning, serious game

I. INTRODUCTION

The term "serious games" refers to any computer games for non-leisure purposes, such as learning and training in a number of application domains. It is initially framed by Abt [1]. There are many examples of entertainment games that contain educational elements, such as Civilization [2, 3, 4, 5, and 6]. Several studies have proved that games and play can be effective to spark a player's interest in learning environments. However, the elements of "fun" are not the main argument [7]. Indeed, as explained by Van Eck [8], games consist of many basic elements that are associated with how people learn. These elements mostly include objective, decision making, problem solving; recall and transfer.

Recently, researchers in game and educational fields have paid more attention to physiological signals like EEG, skin conductance and etc and the interest for further study is quickly growing [9, 10, and 11]. There are increasingly a number of studies that attempt to evaluate the game experience or demonstrate the educational and psychological effects of playing game with physiological evidences. Real-time measurements of a player' physiological signals are indispensable in many studies.

In brief, game-based learning builds upon the belief that "learning by doing" in games. It provides educators a powerful tool. This paper describes a user study that utilizes EEG signals to evaluate the physiological conditions of a player while playing an educational game. The quantitative and qualitative data are analyzed to validate whether a player's physiological signals are valuable indicators to demonstrate the correlation between the intensity of a players' mental activities and his gaming performances.

II. BACKGROUND

In general, being awake and sleeping are two different psychophysiological states. As Yasui pointed out, different psychophysiological states of humans can be recognized by analyzing the measurement of brain activities [12]. To record and interpret electrical activity along the scalp, which is referred to as brainwaves, is one way that helps to understand brain activity in detail.

TABLE 1. EEG SIGNALS AND THEIR FREQUENCY RANGES

Brainwave type	Frequency range
Delta δ	1–3 Hz
Theta θ	4–7 Hz
Alpha α	8–9 Hz (low) 10–12 Hz (high)
Beta β	13–17 Hz (low) 18–30 Hz (high)
Gamma γ	31–40 Hz (low) 41 – 50 Hz (mid)

Brainwaves are created while neurons fire within the brain. Each neuron is electrically charged and then has ions flowing across its membranes. Polarized neurons send signals to their neighbors. So their neighbors become polarized and signal their own neighbors and so on. This movement of polarization stimulates a wave of ions to move through the brain. One way to collect these brainwaves is to attach electrodes to the head. These signals are called as Electroencephalography (EEG). When the ion-wave arrives at the scalp, it interacts with the metal in the electrodes. The device connected to the electrodes then collect, displays the waves. Based on the frequency range, EEG signals are classified several types: delta, theta, alpha, beta, and gamma. The frequency ranges of these major EEG signals are listed in Table 1.

Three brainwaves including alpha, beta, and gamma can be further divided into two sub-bands, such as, low gamma

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and high gamma. Each EEG signal has its own characteristics and is generated from a particular source. Klimesch et al. summarize that every signal reflects a particular cognitive process [13].

- The frequencies of Delta waves are the lowest among all the brainwaves. They become noticeable when a person is in deep sleep. When a person is in conscious, they are minimal.
- Theta waves are typically noticeable in a relaxed state, such as during light sleep and meditation. They become stronger while listening to non-harmonious music or breathing deeply [14].
- Alpha waves appear in meditation and relaxation. They can be amplified while breathing deeply and lying back with the eyes closed.
- Beta waves, on the contrary, are associated with attentiveness and focus [15].
- The frequencies of Gamma waves are the highest. It can be caught while meditating with focusing on a particular object, for example, a dark symbol of some kind on a light surface and repeating a mantra. In Eastern religions like Hinduism and Buddhism, this is a very common technique for meditation [16].

Most of the time, to collect EEG signals is performed by professionals or technicians according to a medical protocol, including positioning electrodes around the head and enhancing the connection between electrodes and scalp. Conductive gel is often necessary to improve the signal quality. However, gel can also cause uneasiness for the subjects, particularly with multiple electrodes, which consecutively can cause inaccurate measurements. In addition, this common practice is tedious since preparing the measurement with a large number of electrodes usually takes lots of time. Furthermore, EEG signals are often contaminated by electrical potentials. These potentials are generated by muscle contractions and regarded as artifacts. There are mainly two categories: ocular artifacts (OA) and muscular artifacts (MA). OA are related to all movement of the eye; and MA are generated while the muscles of the face, scalp, jaw, and head move.

III. WASTELAND ADVENTURE GAME

In order to study the learning effect of serious games, we have picked up one game called Wasteland Adventure (see Fig. 1 left) developed by Grace Peng [17]. This is a game that is concerned with Global Warming. As Global Warming becomes serious, climate changes begin to threaten human's living. Although it has gained more public attention in recent years, most people see the facts but they simply don't believe they can help change this situation. The author aims to persuade people to escape from their intuitive rejection of this serious fact and raise their awareness of the importance of waste recycling. She wants to illustrate how recycling being a simple activity can be taught sustainably and help us to protect our eco-system. The game is designed within a narrative context featuring powerful avatars. A player needs to maneuver the avatar to collect trash as much as possible in order to obtain high score. These actions will help players achieve the goal of this game, which is saving the earth from disaster.

Figure 1. Left: Game Cover; Right: states of the main character – BOBO

Game Story. The story takes place in 3010AD. At that time, humans being have destroyed their eco-system. The consequence is that the earth loses the ability to recover and the environment continuously gets worse. There is no fresh air and clean water. Everyone has to wear a breathing mask in order to protect their lungs from the toxic air. Human beings are facing a critical disaster. There is a main character called BOBO, who is the son of a famous scientist. BOBO collects all kinds of usable garbage that causes the pollution on the earth. He can turn his collection of garbage into toys he likes.

However, BOBO has an evil inside himself. Sometimes, he becomes very lazy. So a player needs to escape from the chase of an evil avatar that symbolizes the main character's lazy attitude.

Figure 2. Three types of trashes: glass bottle, paper box and aluminum can

Game Objective and Levels. The goal of a player is to enable BOBO clean up all three types of trashes that include glass, paper box and can (see Fig. 2) and save the earth. There are three levels in total (see Fig. 3, 4 and 5). A player can progress to the next level by cleaning up all trashes at current level. At level 1, a player has to clean up all paper trash. He/she can either feed them into normal trash bin or recycle paper bin.


Figure 3. Level one of this recycling game

At level 2, a player has to clean up all paper and glass trash. Whether the paper and glass trash should be put into the recycle trash bin or normal trash bin, it is a player's choice.


Figure 4. Level two of this recycling game

At level 3, a player has to deal with paper, glass and aluminum three types of trashes. Similarly, whether the paper, glass and aluminum trash should be put into the recycle trash bin or normal trash bin, it is a player's choice.


Figure 5. Level three of this recycling game

However, when each kind of trash goes into the recycle trash bin, a player will receive higher score than normal into the trash bin. In addition, when one type of trash is put into a wrong type of recycle bin, a player will be punished by deducting his score. When BOBO collides with its evil counterpart - the bad BOBO, the health level of BOBO will decrease. When the health level reaches zero, BOBO has lost his life. In total, BOBO will have three lives. When he loses all his lives, the game will stop at that level. When a player cleans up all the trashes at each level, he automatically moves up to the next level.

Game Control. A player can use the four keys "UP", "DOWN", "RIGHT", "LEFT" on a keyboard to control the movement of the main character - BOBO.

IV. USER STUDY

We have designed a user study in which the brain activities of a game player are monitored while he plays this wasteland game. The NeuroSky MindSet is the device we use to collect EEG signals. It simplifies the measurement process of EEG signals compared with those traditional EEG equipments. It measures the potential difference between the electrode on the forehead, and the reference electrode that is positioned on the left earlobe (see Fig.6). There should be no objects between the electrode and the scalp, which will guarantee a direct touch and enable to collect a stronger, clearer signal. The MindSet device has only one single dry electrode. This makes the measuring and analysis of brain states rather simple and creates easiness for a subject [12]. The reason that measures a single channel EEG signal originated from the frontal cortex is that it corresponds to higher states of consciousness.

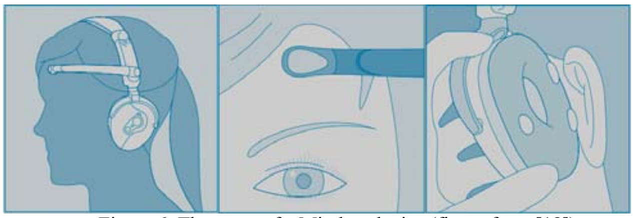
Figure 6. The setup of a Mindset device (figure from [18])

The free and open-source software platform OpenViBE [19] was used to record EEG data from the NeuroSky mindset device. The software platform consists of a set of modules that can be integrated easily and efficiently while formulating an EEG related application. There are a number of useful tools within the software package as well, such as the acquisition server, the designer, 2D visualization tools and some sample scenarios of Brain Computer Interface or neuro-feedback applications. The acquisition server acts as a generic interface to different kinds of acquisition machines, e.g., EEG or MEG systems. The designer is used for system designers to build complete scenarios upon existing software modules with an exclusive graphical language and a simple Graphical User Interface (GUI). In this study, we only intend to collect EEG data from the MindSet device in real time.

Therefore, only three modules of OpenViBE are selected: acquisition client, CSV file writer and signal display modules. The combination of these three modules enables us to observe the EEG data in real time and store them in .csv file format. In every 2 milliseconds, the Mindset device returns Attention value, Meditation value, and the amplitude of single channel EEG signal.

In total, 30 subjects with average age 20 have participated in this study (13 male and 17 female). Before the experiment, each subject must answer one questionnaire in which the basic information, including age, the experience of gaming and etc is collected. After finishing the first questionnaire, participants are briefed about the game and the purpose of the study. A training session is followed in order to give a subject the opportunity to practice with the keyboard and mouse and become familiar with the navigation means of the game. The formal session starts as soon as a subject gives a sign that she/he is confident and proficient with the navigation style. Each player will be asked to play all three levels. The recording of the EEG signals begins once a player indicates that he is ready to play. The timer stops when a player finishes collecting all the trashes at each level.

After the game, subjects will be asked to answer another questionnaire that is associated with the tasks in the game. For example, subjects are asked whether they knew more about the waste recycling. These questions are designed to evaluate whether the specific knowledge of recycling embedded in this game has been transferred to a player. These results will be compared with the scores afterwards. In the end of the experiment, participants are asked to describe their general impressions about the game and give suggestions on how to improve it.

V. RESULTS AND DISCUSSION

A. Pre-questionnaire

In the pre-questionnaire, the information about the age, gender, gaming preference and experiences of each player is collected. Results indicate that 76% of the participants play games occasionally. 20% of the participants often play games. Among the participants who play games, 50% of them play mobile games. 20% of them play network games. The rest of them play standalone PC game. 40% of the participants play games at lease once per week. 30% of the participants play games at least once per day. 50% of the participants become confident when they play games. Only 30% of participants recognize computer games as their hobby. 50% of participants like to play strategy games. 25% of participants like to play fighting games.

B. PlayTime and Score on Task

The total time spent on the game and score received of each player at each level are recorded. Average time spent on each level with 95% confidence interval of all 30 subjects is summarized in Fig.7. Total time spent on level 1 was descriptively higher on level 2 and level 3. The results of within-subject analysis indicate that in terms of the play time, the difference is significant among three levels (DF=2, F=17.291, p=0.00<0.02). Average score received at each level with 95% confidence interval of all 30 subjects is illustrated in Fig.8. Total score received at level 3 (Fig.8) was descriptively lower at level 1 and level 2. The results of within-subject analysis show that in terms of the score received, there are significant differences among three levels as well (DF=2, F=154.739, p=0.00<0.02).

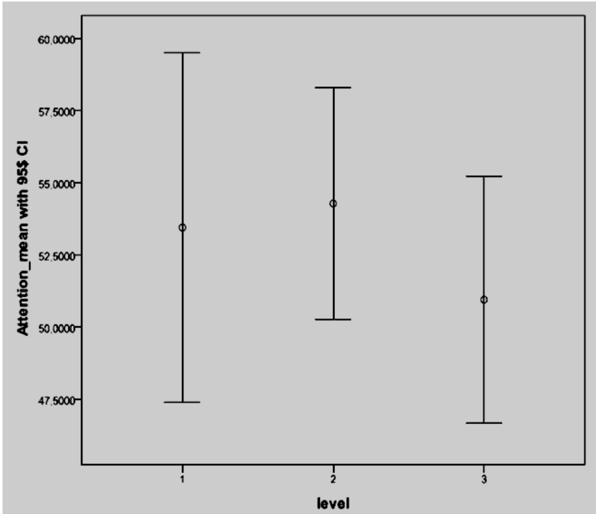

Figure 7. Average play time in second at three levels.

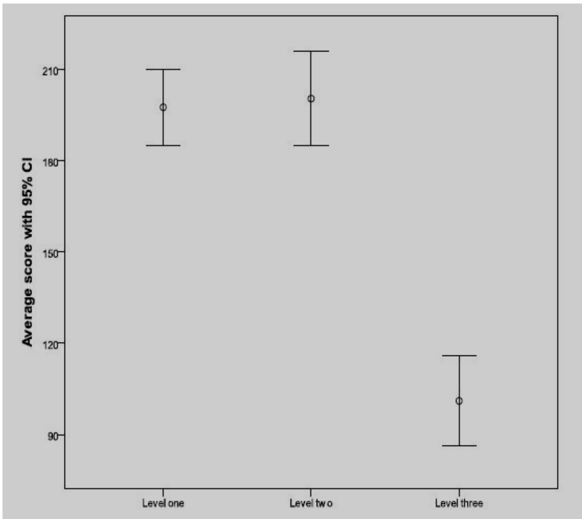

Figure 8. Average score at three levels

In addition, we investigate whether there is any correlation between the play time and task performance for the entire population of the players at each level. At level one of the game, there is a correlation between the play time and the score. The Pearson correlation coefficient, r, is -0.653, and that is statistically significant ($p = 0.00 < 0.05$). At level two of the game, there is no correlation between the playtime and the score. The Pearson correlation coefficient, r, is -0.342, and that is statistically insignificant ($p = 0.065 > 0.05$). Additionally, there is a correlation between the play time and the score at level three. The Pearson correlation coefficient, r, is 0.485, and that is statistically significant ($p = 0.007 < 0.05$).

C. Performance and Physiological Measurement

NeuroSky has developed a particular algorithm in order to describe mental states. There are several parameters called eSense. eSense is calculated after the raw brainwave signals are amplified and the ambient noise and muscle movement are removed. There are two types of eSense values called Attention and Meditation. The meter value is reported on a relative scale of 1 to 100. On this scale, a value is between 40 and 60 at any given moment in time is considered as “neutral” and is similar in notion to “baselines”. The eSense Attention value indicates the intensity of a subject's mental “focus” or “attention”. The value increases during intense concentration and directed (but stable) mental activity. The eSense Meditation value describes the level of a subject's mental “calmness” or “relaxation”. It should be noticed that Meditation is the measure of a person's mental states, rather than his physical levels. Therefore, simply relaxing all the muscles of the body may not immediately increase a Meditation level. The Attention level will be low while a subject is in a state of distractions, wandering thoughts, lack of focus, or anxiety. On the other hand, distractions, wandering thoughts, anxiety, agitation, and sensory stimuli may cause the Meditation meter level lower.

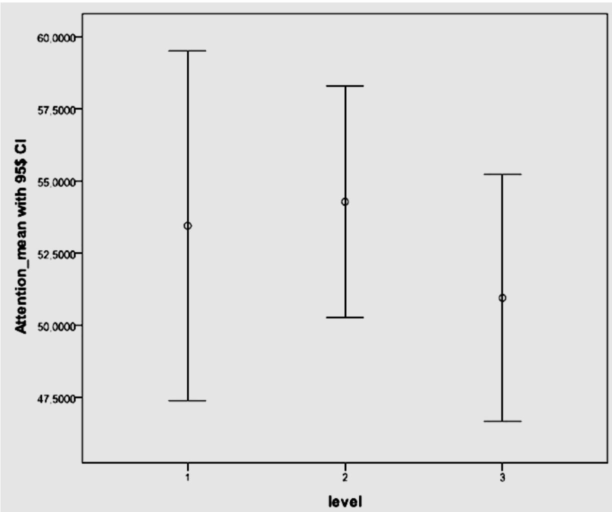

Figure 9. Mean of the attention at three levels

In this experiment, with a NeuroSky Mindset device, we collected three types of measurements: raw EEG signals, attention and meditation values. The experimental analysis is mainly based on attention and meditation data. The mean and variance of attention and meditation measured at each game level is summarized in Fig.9, Fig.10, Fig.11 and Fig.12. One–way ANOVA analyses indicate there is a significant difference on the variance and standard deviation of the meditation among three game levels ($F_{variance\_meditation}$=4.11, p=0.02<0.05; $F_{std\_meditation}$ =3,856, p=0,026<0.05).

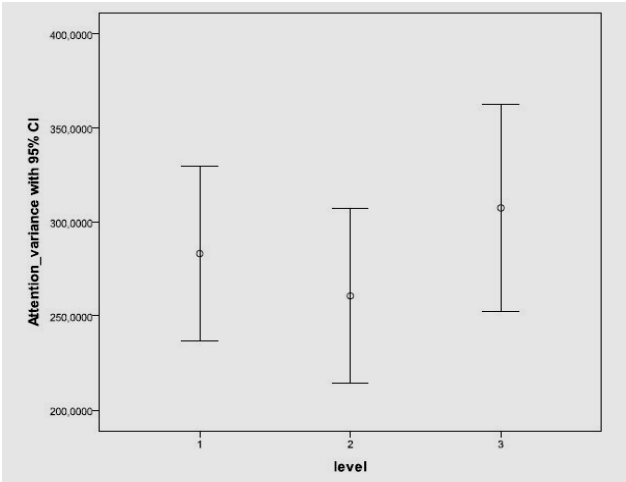

Figure 10. Variance of the attention at three levels.

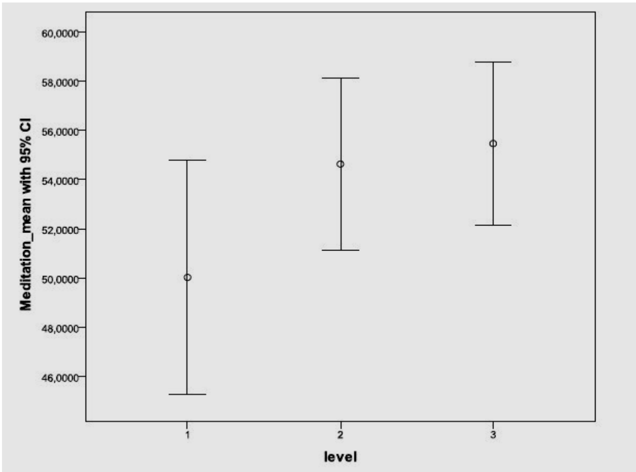

Figure 11. Mean of the meditation at three levels

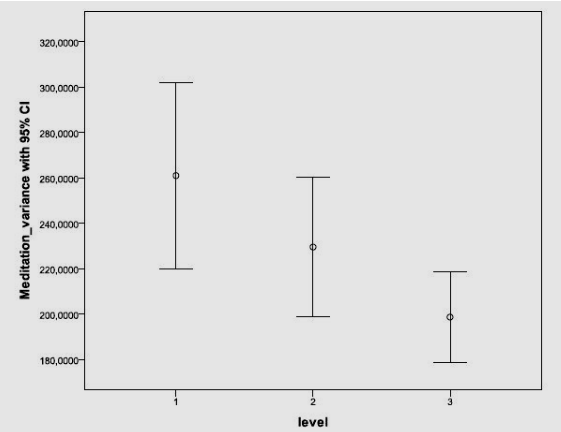

Figure 12. Variance of the meditation at three levels.

VI. CONCLUSION

Computer games, especially 3D games, become increasingly popular among young people. Hence more and more educators turn them into educational tools. As a result, the number of educational material which contains both pedagogical and game-like fun elements is increasing. At the same time, researchers growingly make use of physiological signals to measures the mental state of a player in order to gain better understanding the effect of a game. In this paper, we presented our study on investigating how a serious game facilitates the knowledge transfer of waste recycling. The game designer utilizes digital game to engage people and foster their awareness to protect our environment. A specific educational scenario is embedded into the game where a player is challenged to act a role and complete carefully-designed pedagogical tasks. 30 subjects were invited to experience the game so that the pedagogical effects are measured. EEG data were collected during the study with the help of the Mindset device. Results show that playing this game indeed can be a good way to assist a player in learning the relevant knowledge of waste recycling. Gaming experience of a player can have positive impacts on his performance in terms of playing time. Significant differences were found with respect to playing time and score among three game levels due to the differences in difficulty. In addition, direct correlation was found between playing time and gaming performance, which indicates that the pedagogical effect of a learning game is enhanced as the playing time increases. Future study on this game will be including other physiological signals like hear rate, skin conductance to measure the physiological state of a player. Further user study on a player's behavior with the help of multi-channel EEG measurement is also within the interest.

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