Affective Pacman: A Frustrating Game for Brain-Computer Interface Experiments

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Abstract. We present the design and development of Affective Pacman, a game that induces frustration to study the effect of user state changes on the EEG signal. Affective Pacman is designed to induce frustration for short periods, and allows the synchronous recording of a wide range of sensors, such as physiological sensors and EEG in addition to the game state. A self-assessment is integrated in the game to track changes in user state. Preliminary results indicate a significant effect of the frustration induction on the EEG.

Keywords: Brain-Computer Interfaces, EEG, physiological sensors, frustration, affective computing, Pacman.

1 Introduction

A brain-computer interface (BCI) provides a direct communication link between the brain of a subject and a computer. The brain signal can be used to control the computer, and indirectly other devices. BCI have mostly been applied in medical settings, for example to enable patients with Amyotropic Lateral Sclerosis (ALS) to communicate. In this paper however, we focus on the application of BCI in computer games.

The use of BCIs in computer games poses some additional challenges. We use electroencephalogram (EEG) sensors to record the electrical brain activity for the BCI. The EEG signal is known to be very sensitive to other sources of electrical activity, such as eye (electrooculogram, EOG) and muscle (electromyogram, EMG) movement. Besides these well-known influences, we expect that the user-state can be influenced by both the content of the game and the quality of BCI control, as current BCIs do not yet provide perfect recognition rates. Our goal is to make BCIs useful for gaming. Hence our BCIs should be robust against changes in the user state during game play, such as frustration caused by a malfunctioning BCI.

We will introduce the design of a Pacman game that we can use to investigate the influence of frustration on the EEG signal. We have chosen to focus on an actual movement paradigm, in contrast to the more common imaginary movement paradigm. This means that the user controls the game using real button presses, and we record the EEG only for off-line analysis. Because actual movement is

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very similar to imaginary movement [7], we expect our results to generalize to imaginary movement paradigms.

2 Previous Work

The induction of frustration has already been studied a few times in the context of interactive games. For example, Scheirer et al. [8] used a game in which the mouse failed to respond correctly at random intervals to induce a state of frustration in users, and collected physiological, behavioural and video data. A classifier based on Hidden Markov Models could correctly predict the user state based on the physiological signals of skin conductivity and blood volume pressure 67% of the time. Klein et al. [5] designed a human-computer interaction system that actively assists the user in recovering from negative emotional states using active listening. The experiment induced frustration by stalling the main character of an adventure game similar to the setup of Scheirer et al.. The system was evaluated by comparing with a condition in which the emotions are ignored and a condition in which the user could vent their emotions to the computer. Stalling the game did frustrate the user significantly more than the normal condition.

Diener and Oertel [4] performed a set of experiments using a modified Tetris game in which they identified, recognized and visualized affective states of the player. Affective states could be recognized from the physiological signals with accuracies of up to 70%. For evaluation of the affective states, the Self Assessment Manikin (SAM, [2]) was used. The four quadrants of of the valence-arousal dimensions were used as target affective states, as well as a “loss-of-control” condition in which 20% of the keyboard commands were ignored. These three studies seem to indicate that a malfunctioning control device can be used to frustrate the user on purpose.

A BCI controlled Pacman has already been created by Krepki et al. [6]. They implemented a BCI based on Lateralized Readiness Potential (LRP)[1] that was used to rotate Pacman. The BCI was trained using three to four sessions of seven minutes of training in which the user pressed keys at will (self paced), or performed imaginary movement in response to a cue. During the game, the user could make a decision every two seconds.

3 Design

In this section we describe the design of the Affective Pacman game. We will start with a short description of the requirements, describe the design of the game and finally the design of the experiment for frustration induction using Pacman.

3.1 Requirements

In our experiment we are comparing a condition with normal user interaction with a condition with frustration caused by malfunctioning controls and game

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[1] The LRP is a slow negative EEG shift that develops over the activated motor cortex during a period of about 1 second before the actual movement onset.

response. As EEG is known to be a non-stationary signal, we need to spread our conditions evenly over the experimental session, and change conditions often. To verify that we are inducing frustration, we will use a self assessment after each condition. Because of our frequent changes of conditions, this self assessment has to be integrated in the game in order to minimize the strain on the user. And finally, the frustration manipulation needs to be hidden from the user to prevent the user from accepting it as a part of the experiment.

3.2 Game Design

The game is a Pacman clone close to the original: Four ghosts roam through a two dimensional maze, and for each level the goal is to eat all the pellets without dying. Points are scored for pellets eaten, and Pacman dies when touched by a ghost. When all the pellets are eaten, Pacman advances to the next level.

One major difference with other Pacman implementations is that our Pacman game implements **two button control**; the left shift-key of the keyboard turns Pacman 90° counter-clockwise, the right shift-key turns Pacman 90° clockwise. This allows us to let the user rest both hands on the keyboard, and play the game with index-finger movements. This configuration was chosen because the area on the motor cortex corresponding to left and right hand are far apart, and can therefore be used for BCI control. As in the original it is not possible to stop moving; only when Pacman hits a wall he stops. When Pacman turns in our game, he keeps moving in his last direction until he can move in the new direction. Corners can thus be taken far in advance, but reversing direction in a long corridor requires two turn commands to take effect. As this takes some time to get used to, the first level acts as a tutorial level in which the user can practise the two-button controls.

The game keeps track of the current high score, and displays this high score and the current score on the top-right screen corner to stimulate the user to set a new best.

3.3 Experiment Design

The experiment is built from 2 minute blocks in which frustration is, or is not induced. To keep the game enjoyable only one third of the blocks are of the frustration condition. The blocks are evenly distributed over the session by shuffling lists of 3 blocks (2 normal, 1 frustration) and adding these together. To frustrate the user we manipulate both the user input and the visual output. We randomly miss 15% of the key presses, resulting in a barely playable game. The screen freezes for two to five frames at 25 frames per second with a probability of 5%.

After each block, we assess the user state using the Self Assessment Manikin (SAM, [2]). The user can use the numeric keys on the keyboard to choose a point on the Likert-scale below the pictograms for respectively the valence, arousal and dominance axis (Figure 1). After pressing three digits, the experiment returns to the game that can then be resumed. We expect to measure a shift towards negative valence, higher arousal and lower dominance after each frustration block.

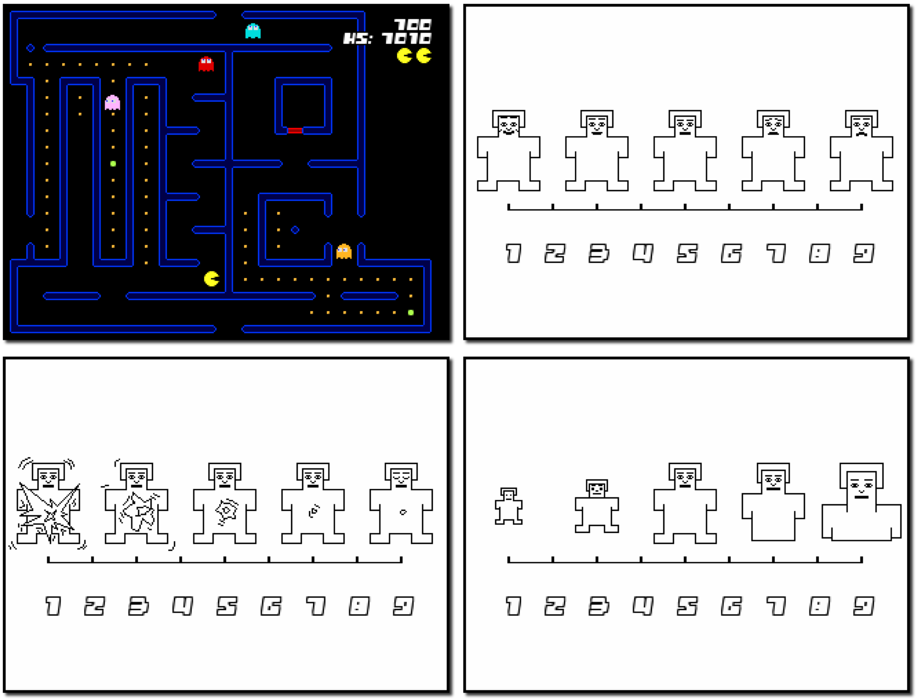

Fig. 1. From left to right, top to bottom: A screen shot of the third level, the SAM for valence, the SAM for arousal and the SAM for dominance

4 Sensors and Recording

We use our BioSemi ActiveTwo EEG system to record the EEG and physiological sensors. For EEG we use 32 Ag/AgCl electrodes at the positions of the Extended International 10-20 system. To measure and filter the influence of ocular and muscle artifacts we record the EOG (bipolar horizontal and vertical pairs) and EMG signals of the finger movement used to press the game controls.

In addition to these sensors, we measure the galvanic skin response (GSR), the heart rate, respiration, temperature, and the blood volume pressure (BVP). Both the EEG and physiological sensors are synchronized in hardware with event markers written from the game. The same physiological sensors were used by Chanel et al. [3] to detect boredom and anxiety in a Tetris game, resulting in significant differences for GSR, heart rate, respiration and temperature.

5 Preliminary Results

For our first subject we compared the Event Related Desynchronizatoin (ERD) related to the different key-presses in the game. The ERD is a decrease in band-power over the motor cortices related to motor activity. The EEG-data was

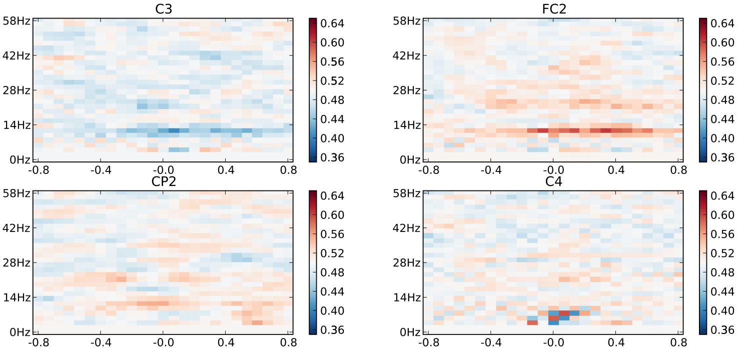

Fig. 2. Time-frequency plots for the EEG sensors C3 (left motorcortex), FC2, CP2, and C4 (right motorcortex). The colors indicate the AUC for left versus right, blue indicates more power in the left condition, red indicates more power in the right condition. Both C3 and FC2 show significant ERD-related differences around 12Hz. The key-presses are aligined at timepoint 0.

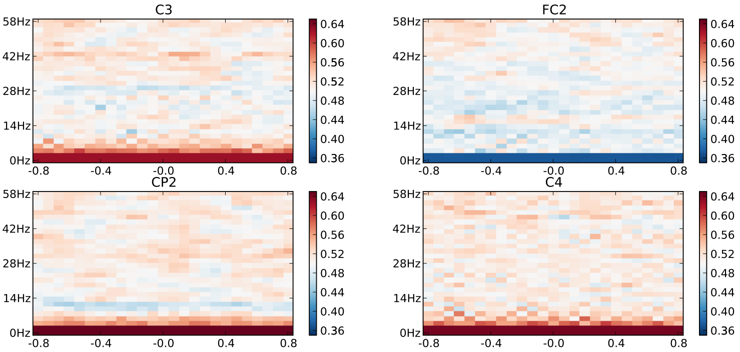

Fig. 3. Time-frequency plots for the EEG sensors C3 (left motorcortex), FC2, CP2, and C4 (right motorcortex). The colors indicate the AUC; blue indicates more power in the frustration condition, red indicates more power in the normal condition. The delta and theta-band are significantly different, but also around 12Hz differences can be observed (FC2, CP2).

re-referenced to the common average reference (CAR). After re-referencing, two seconds surrounding a key-press were extracted. These instances were transformed into a time-frequency representation using a Short-Term Fourier Transform (STFT). We used the area under curve $(\mathrm{AUC})^2$ of the Receiver Operating Characteristic (ROC) to compare left and right hand movements (Figure 2). Both motor cortices display significant differences ($p \leq 0.05$, Agarwal et al. [1]). This difference in bandpower indicates an ERD, that could be used for

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[2] The AUC is a ranking statistic equivalent to the Wilcoxon-Mann-Whitney statistic.

classification. The right motor cortex (C4) displays an interleaving pattern around 8Hz that could be related to the LRP.

Now that we have verified the presence of ERD, we can compare the normal and frustration condition, hoping for a difference in the frequency ranges relevant for the detection of motor activity. Figure 3 show differences between the conditions. The differences in the delta-band (up to 3 Hz) and theta-band (4–7 Hz) are significant ($p \leq 0.05$), but also around 12Hz where the ERD for this subject manifests itself differences are visible. This is a observation that supports the hypothesis that the frustration could deteriorate BCI performance.

6 Conclusions and Future Work

We have presented the design of Affective Pacman, a game that allows us to research the effects of frustration on BCIs used in games. The game is designed to induce frustration for short periods, allows synchronous recording of a wide range of sensors.

The users report that the control of Pacman is challenging, and they assumed that the frustration induction was a bug in the game. This indicates that the method of induction is not too obvious, as is required for a successful experiment. Our preliminary analysis already revealed significant differences between the normal and the frustration condition, and indicates that features used for classification could be affected. A bigger test with ten to twenty users is planned in the near future. The real influence of frustration on BCI performance will be measured by training a BCI on data of the normal condition, and test on both unseen normal blocks and unseen blocks of the frustration condition.

A nice by-product of this experiment is that the SAM could indicate user changes over time, such as boredom, fatigue etc. If such a trend is found we could try to relate it to the BCI performance or even directly to the EEG. Future versions of the game could let the user play using the keyboard until the BCI has reached a acceptable performance level, and then transparently switch to brain-controlled game play.

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