"Brain Invaders": a prototype of an open-source P300-based video game working with the OpenViBE platform.

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We have developed the prototype of a pure-BCI video game based on the well known vintage video game "Space Invaders". In our "Brain Invaders" a number of aliens are displayed in a grid and the player has to destroy a particular alien, the target, only by concentrating on it. The game makes use of a state-of-the art P300 oddball paradigm to select the alien to be destroyed at a regular pace, based on current probabilities assigned to each alien by a learning machine continuously analyzing and classifying the user's electroencephalographic stream (the Open-ViBE platform). As compared to the standard P300-speller paradigm our game may optionally use: 1) flashing items in random groups and no longer by rows and columns; 2) variable inter-stimulus intervals drawn from an exponential distribution; 3) magnification of flashed target items. Preliminary tests show an excellent transfer rate, since starting with 36 aliens on the screen, one to three repetitions typically suffice to destroy the target alien. Our development is completely open-source and will continue to improve further the signal processing and classification algorithms, besides the paradigm itself, the gameplay and the BCI ergonomy, in order to achieve a "Plug & Play" video game suitable for the large public of gamers.

1. Introduction

A P300-based Brain Computer Interface (BCI) enables the user to successively select symbols among an available set, without relying on any motor command. The symbols can be of any kind, such as alphanumeric characters (e.g., for spelling) or icons (e.g., the elements of a menu in a computer application). These BCIs exploit the well-known oddball paradigm, in which an infrequent task-related item (the target symbol) elicits a P300 Event-Related Potential (ERP) (Wolpaw et al., 2002). By flashing symbols exhaustively, either one-by-one or in groups, it is possible to estimate the probability of each symbol being the one selected by the user. This is achieved evaluating the P300 elicited by each symbol once it has flashed. The complete set of flashes must be repeated a number of times to obtain reliable ERP estimations by means of trial averaging. The distinctive advantages of P300-based BCI are that the alphabet (the set of all available symbols) can be large (hundreds of symbols) and that 100% accuracy can be obtained when allowing a sufficient number of repetitions. That is to say, with P300-based BCIs there is a direct trade-off between accuracy and transfer rate. In this work, the low transfer rate is not considered a limitation, rather a challenge for the player, along the line of the reasoning in (Nijholt et al. 2009). Nonetheless, we aim at a video game flowing with a sustained pace. For this reason we have implemented three improvements over the basic P300 BCI paradigm.

2. Method

Among the three (optional) improvements over the basic P300 paradigm (Farwell and Donchin, 1988), only the third takes advantage explicitly of the a-priori target knowledge; the first two can be applied to any P300 BCI:

1) In the original P300-speller paradigm symbols flash by rows and columns. Often detection errors arise because of the "adjacency-distraction" phenomenon (Jin et al., 2011; Townsend et al., 2010); non-target symbols in rows or columns adjacent to the target attract the user's attention when they flash, producing a P300 that makes the detection of the target P300 more difficult. To mitigate this effect we flash the symbols by random groups. Let the pair (r, c), with r :{1,…,R} and c :{1,…,C} be the ordinal indexes of the row and column position of each symbol, whit R rows and C columns in total. It suffice to create a supplementary index table with entries ($x[r]$, $y[c]$), where x :{1,…,R} and y :{1,…,C} are ordinal indexes shuffled at each repetition and flash the symbols according to these new indexes. Not only the "adjacency-distraction" effect is mitigated,

we also obtain that the pattern of flashing becomes totally unpredictable, which is expected to sustain the attention of the gamer. Furthermore, by flashing in random groups there is no apparent difference between a "row" and "column", thus we can flash all rows then all columns (or vice versa) rather than rows and columns alternately. Hence, the probability that the target symbol is included in two successive flashes, which is known to worsen the target detection, is only 1/(RxC). Of course, one may generate pseudo-random sequences to avoid also this little probability, but we did not go into such tricks. Noteworthy, random-group flashing allows arbitrary positioning of the symbols on the screen (no more need to arrange symbols on a grid), which greatly expand the usability of the P300 paradigm.

2) Usually, the stimulus interval (the flashing time) and the inter-stimulus interval (ISI: the time between two flashes) are kept constant. The periodic flashing is annoying and tiring because the visual cortex is driven to oscillate at the flashing frequency, which is usually far away from the natural talamo-cortical loop oscillation of this region, which is in the alpha range (8-12 Hz). Furthermore, the periodic flashing makes the flashing pattern predictable and boring. To eliminate all these effects we may use random ISI drawn from a random exponential distribution. The exponential distribution (also called "waiting-time" distribution) with parameter λ and population mean(sd)=$1/\lambda(1/\lambda)$ is the distribution of the time passing in between two events of random series following a Poisson process with the same parameter λ and population mean(sd)=$\lambda(\sqrt{\lambda})$, that is a process in which events occur continuously and independently at a constant average rate. For example, it is the natural distribution for modeling time between system failures, telephone calls, customer arrivals, accidents at a street intersection, etc. Random ISI uniformly distributed in between 450 and 550 ms have been successfully used in a P300 BCI by Allison and Pineda (2003).

3) In a previous research conducted within the OpenViBE ANR project it has been found that magnifying (increasing the size of) the flashed symbols improves the P300 amplitude and ensuing classification accuracy [Gibert et al., 2008]. In this work, we magnify during flashing only the target symbol, by 30%.

The Brain Invaders works by rounds. In each round a 6x6 grid of aliens is displayed on a black background. Aliens are all displayed grey with the exception of the target which is displayed in red. The group flashing is achieved displaying the non-target symbols with a lighter gray and the target symbol with its complementary color (cyan). The choice of the complementary color is natural as it creates maximum contrast on the color wheel. As in the original "Space Invaders", aliens move altogether from side to side of the screen continuously and move from top to bottom by one step as they touch either screen border. Figure 1 (left) shows a random group flashing and target magnification. At each repetition the system assigns to each symbol the probability of being the target according to the signal processing and classification method implemented in the OpenViBE platform (the xDAWN spatial filter [Rivet et al. 2009] followed by a Linear Discriminant Analysis classifier) and destroys the alien with the highest probability (Figure 1, right). If this alien is the target the round ends, otherwise this alien is eliminated and another repetition of flashes starts. The process is continued until the target alien is destroyed or until 14 non-target aliens have been destroyed, after which another round starts. Between two rounds, the points obtained in the last round and the cumulative score are shown to the player. The points obtained at each round are inversely proportional to the number of repetitions necessary to destroy the target (NRD). The flashing time is fixed and equals 60 ms. The ISI, as aforementioned, is randomly drawn from an exponential distribution with mean 1 (λ=1), multiplied by 100 to obtain a mean ISI of 100 ms. and bounded in the range [20…500] ms by drawing a random number until it falls in this range. The destruction is almost instantaneous after the last flash. Then a 3 sec break is allowed to relax and move freely, after which the new round starts. A collection of rounds is named blocks. Typically a block is comprised of six rounds. Between rounds a 30 sec break is allowed. A game session is made of several blocks.

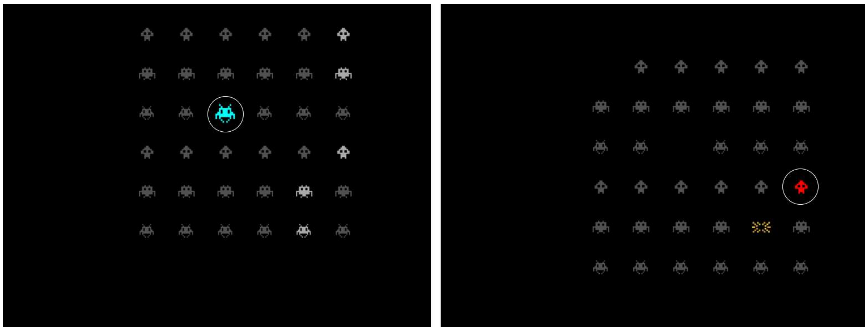

Figure 1.Screen shots of the "Brain Invaders". On the left it is shown the flashing of a random group including the target (circled in the figure, but not in the game), which is magnified by 30% during flashing. The flash is within the first repetition (no alien has been destroyed yet). On the right it is shown the destruction of a non-target alien at the end of the third repetition (two non-target aliens have been already destroyed after the first two repetitions of this round).

The implementation of the "Brain Invaders" is achieved with three software modules, 1) acquisition, 2) processing and 3) rendering. Since they communicate to each other via a TCP/IP protocol, they may run on a single computer or on distinct computers in any combination:

1) Acquisition. This is the Open-ViBE acquisition server (Renard et al., 2010). It is in charge of acquiring the data from the EEG machine, streaming the data, correcting for possible amplifiers drifts and sending the data to the Open-ViBE platform (Renard et al., 2010; http://openvibe.inria.fr/) for analysis.

2) Processing. The Open-ViBE platform performs data analysis on-line. At the end of each repetition it computes the probability of each alien being the target and sends to the rendering application the indexes of the alien with the highest probability.

3) Rendering. The visual rendering module, written in C++ using the Ogre3D engine (www.ogre3d.org), runs the user-interface. It manages target destruction and the sequence of trials in blocks. It is in charge also of tagging the flash onset/offset via parallel port directly into the EEG acquisition machine. We use a 120Hz monitor.

3. Results

We have tested the prototype on four BCI-naif healthy subjects (S1…S4). S1 and S2 played with the random group flashing set up, whereas S3 and S4 played with the usual row-column flashing. The training was composed of 10 times 8 repetitions, lasting approximately three minutes only. The test was composed of six blocks of six trials each. EEG was acquired on a Mitsar EEG-202 amplifier (Mitsar, St. Petersburg, Russia) using an elastic cap (Electro-Cap, Inc., Eaton, USA) holding 31 sylver chloride electrodes uniformly positioned all over the scalp according to the extended 10-20 system and referenced to both earlobes linked digitally. The sampling rate was 500 sps and an acquisition band-pass filter in the range 0.1-70 Hz was enabled. The mean (sd) number of repetitions necessary to destroy the target (NRD) over the 36 trials was 2.06 (1.07) for S1, 1.5(0.65) for S2, 1.33 (1.34) for S3 and 3.56 (3.43) for S4 (Fig. 2). For this experiment 89% of trials required at most three repetitions to destroy the target. For S2 and S3 this was true for 100% of trials.

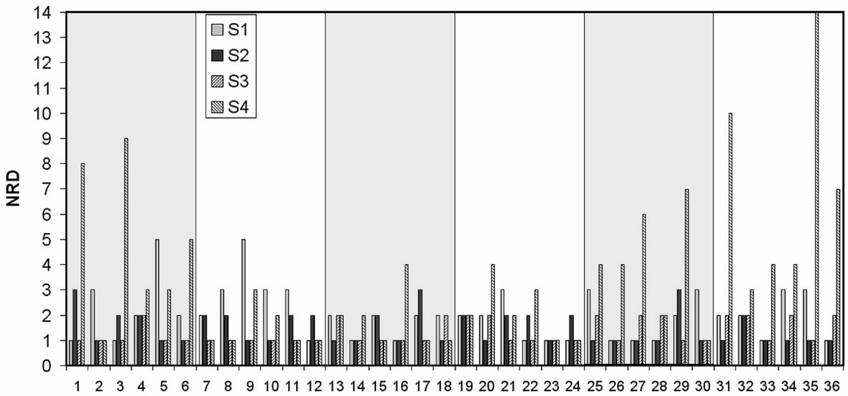

Figure 2. Number of repetitions necessary to destroy the target (NRD) on the y-axis for each trial (x-axis) for four BCI-naif subjects. The vertical bands indicates the six block, composed of six trials each.

4. Conclusions

Our development is open-source and available to interested peers. This research is a starting point of an ongoing program. Our goal is to achieve a "Plug&Play" game suitable to the large public. To this end, our next priority is to get rid completely of the learning phase by devising an adapting learning algorithm initialized using the average optimal setting obtained on a large database. Then, we will work on the gameplay, adding on the foreground animations becoming progressively more distracting as the number of blocks progresses. Meanwhile, further research is being carried out at GIPSA-lab to improve the ERP single-trial extraction and classification, besides the BCI paradigm itself.

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