Intelligent Biofeedback using an Immersive Competitive Environment

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ABSTRACT:

In this paper we introduce the idea of enhancing biofeedback by placing it within a competitive virtual gaming environment. This is an example of a new concept to be called '*Affective Feedback*'. In essence this term means that the computer is an active intelligent participant in the biofeedback loop. The relationship between human and machine is now two way - the computer is affected by the state of the human and vice versa. We demonstrate the concept through a simple video game where two people compete in a race based on the relaxation levels of the players. The competitive virtual environment affects the players' level of relaxation while the levels of relaxation determine the outcome of the game. The person most relaxed wins the game.

INTRODUCTION - BIOFEEDBACK TO AFFECTIVE FEEDBACK:

If a person is provided with real-time information about a certain aspect of their physiology, they can determine the way that their mental changes affect this state. Over time, the person can learn, consciously or subconsciously, how to control this aspect of their "bio-state." This process is known as *biofeedback* and can be used to gain mental control over brainwaves, blood flow, muscular action, and many other physiological events. For example, many studies have shown that, over time, people can gain control of their brainstate (as measured by an electroencephalogram [EEG]) when given a graphical or auditory representation of their EEG.[1] Biofeedback has many clinical applications and has been used to treat a wide range of conditions, from attention deficit disorder(ADD)[2] to addiction[3].

Affective Feedback is a hybrid of traditional biofeedback and "affective computing," a term coined by Rosalind Picard meaning "computing that…arises from or deliberately influences emotion."[4] The basic idea is to make the *framework* in which the biofeedback takes place directly influence and affect the "bio-state" of the user. In other words, the person is not only affected by the feedback information about their bio-state, but also by the way that it is presented.

An example of a simple way of achieving this goal will be presented in this paper. We have created a two-player competitive racing game which is based on the players' level of relaxation, as measured by their galvanic skin response. The basic idea is simple: As a player relaxes, their character moves faster. Therefore, the person who relaxes most wins the race. In some sense, this is traditional biofeedback: The person is given feedback information on their level of relaxation by the action of their dragon. However, the key difference is that the environment is designed to affect the user. First of all, the game takes place in a visually stunning virtual 3-D world. This type of environment has been shown to draw more of the user's attention and make the feedback more effective.[5] In addition, the game provides a much more appealing and effective "reward" for achieving the correct "bio-state." Studies have shown that more "meaningful" reinforcement makes biofeedback more effective, especially in children.[6] Finally, and most important, the competitive framework has a profound affect on the mental state of the user. Competitive games are normally associated with tension and stress, so the player must learn how to override this tendency and learn not only how to relax, but how to relax in a tense environment.

This game demonstrates a small but important step into the next age of intelligent, ubiquitous computers: Computers with the ability to recognize, react to, and affect our physiological state in a meaningful way. Currently, we are working to expand the concept by adding other bio-state measurements and creating a more "intelligent" interface. The hope is that, in the future, we will be able to create a game in which the computer actually "learns" which environments foster different mental states in individual users, and uses this information to affect and reinforce the user's target "bio-state." In some sense, the computer would be performing its own biofeedback as it is changing the environment and recording how the user reacts. Traditional biofeedback is a standard feedback loop: The user learns to control their state based on information presented on a computer. Affective feedback creates another loop: The computer learns how different environments and frameworks affect the user and adjusts accordingly.

It is important to note that, just as biofeedback can be administered without this new loop, affective feedback is possible without traditional biofeedback. If the computer "knows" how different situations and environments can affect the user's state, it can change based on the needs of the user. This research has large potential for interesting expansion and, given the clinical applications of biofeedback, a good chance of genuinely improving peoples' lives.

IMPLEMENTATION:

Our game, called "Relax-to-Win," is a competitive two player racing game. Each player controls an animated 3-d dragon in a virtual race-track environment where the goal is to cross the finish line first. While the game itself is quite visually impressive, the main value lies in the fact that the player's stress level, as measured by their galvanic skin response (described below), controls the action of the dragon. The dragon has three successively faster "states;" walk, run and fly. If a player relaxes, their skin resistance increases and the dragon will shift up to the next faster state. Conversely, an increase in "stress" causes the dragon to shift to a slower state. The end result is that the player who "relaxes the most" over the game will reach the finish line first. Generally, due to the length of the virtual track, games last about 40 seconds.

The two major issues in implementation are producing an accurate measure of "relaxation" and creating a way to use this measurement to determine when the dragon shifts to a faster or slower state. We chose to use galvanic skin response (GSR) to measure relaxation. As a person becomes more stressed, their sweat glands begin to open and secrete sweat. Although we cannot measure this phenomenon directly, as sweat glands turn "on," they form a low-resistance pathway from the surface to the deepest layers of the skin. This presents the opportunity to measure the activity of the sweat glands by applying a small voltage to human skin, inducing a current to flow between two contact points. The voltage/current ratio is a person's instantaneous skin resistance, or GSR, and is a proxy for sweat gland activity and hence a measure of relaxation. [7]

Accurately measuring GSR is very tricky, so we acquired a Biopac biosensor system complete with two independent GSR channels. The Biopac's combination of electrode current-injection measurement, selectable decade amplifiers, and a clean output make it very accurate. The Biopac system, however, is expensive and bulky. The whole setup costs approximately £13,000 ($14,000) and takes up as much space as a desktop computer. As our game is partially intended for home or therapeutic use, we wanted to find a cheaper way to achieve accurate measurements. Our new custom measurement device is a bio-amplifier that possesses the accuracy of the Biopac system, but costs less than £40 ($43) to produce and is about the size of a postage stamp.

Once the skin conductance has been transduced, filtered, and amplified, it is digitized and passed to the game engine via a National Instruments data acquisition unit. Then, the second issue arises: Determining a method to process the signal in a "meaningful" way. The extremely individual nature of GSR (there are no "normal" baselines for people) makes it virtually impossible to directly compare GSR measurements across individuals.[8] However, regardless of the baseline reading, if a person is relaxing, their skin resistance will increase. Therefore, we decided to use the general trend of the GSR measurement over a certain time period as our gauge of relaxation during that period. This erases the problem of baselines and possesses the added bonus that, at any point in the game, if a person begins to relax, they are instantly rewarded. Our algorithm takes a set of points and does a least squares approximation to calculate the slope of the best-fit line. Depending on the sign of the slope, the dragon's "need for speed" increases or decreases. When the "need for speed" quantity passes certain threshold values, the dragon's state changes and it speeds up or slow down.

Once we began to demonstrate the game to people, we noticed that our players' stress levels jumped up immediately after they were connected to the equipment. This is presumably due to the implicit stress of a new environment, the fact that the players are the center of attention, and the competitive nature of the game. To reduce this problem, we created a minute-long movie that plays before the game. The movie uses 3-D animation and relaxing music to tell the story of the dragon race. It allows the players to get comfortable and draws attention away from them, reducing their stress levels when the game begins. In addition, although our current method of processing the GSR signal does not require baseline readings, it is possible that in the future we will use a different measure of relaxation or a different method of processing that does. The trailer would provide interesting and relaxing stimuli while we take these readings.

DISCUSSION:

The point of our game was to demonstrate the concept of affective feedback. After multiple demonstrations to various people, the game has exceeded our expectations.

To begin, it is clear that the competitive framework which houses the biofeedback has a pronounced affect on the players. The standard reaction to this type of game is to increase awareness and stress in order to compete better. The problem is that, in this game, stress causes the player to lose. Therefore, the players have to learn how to override their natural inclination and relax. When people play the game for the first time, it is clear by their performance that this is not easy. However, as they continue to play, they gain more control over their stress and start to perform better. It is interesting to note players' reactions to different scenarios. Often, if a player begins to lose, it will cause them to become more stressed and fall further behind. Once the other player wins and the competition is over, the loser will often begin to relax and their dragon will fly to the finish line.

Overall, the game did seem to enhance the biofeedback. The competitive nature of the game combined with the virtual setting caused the players to very aware of their performance, a key factor in effective biofeedback. In addition, as the players had a real interest in winning the game, they were highly motivated to control their GSR, another important component of biofeedback. Finally, we believe that biofeedback training in this setting is more versatile than standard biofeedback. Learning how to relax in a stressful environment allows people the power to stay relaxed in more situations.

In our trials, the players' personal experiences support these conclusions. Many reported that, at first, they were unable to control their stress. However, after playing multiple times, most gained more control or were at least more aware of the causes of their stress. The most meaningful comments came from people who seemed to discover methods that helped them relax. Players who are stressed (and therefore lose) on their first try are often able to win races after only two or three attempts.

Though simple in concept, "Relax to Win" marks a powerful step forward in the world of computer gaming. To oversimplify a bit, most traditional games encourage players to learn to push a combination of buttons at the correct time in the correct order. In a typical first person shooter, for example, the players learn to traverse a labyrinthine environment (by pushing buttons), and destroy their fellow players (by pushing more buttons). By using a new and unfamiliar form of input, not only have we restored the novelty of the computer game, we have once again leveled the playing field. With our system, the most seasoned gamer in the world has little advantage over the newest of computer users, because the lightning-quick reflexes and solid hand-eye coordination which they have developed don't come into play. By making something so new yet so simple, we have in effect created the new Pong.

FUTURE:

Although it is an effective proof of concept, our system is only in its infancy. The input is unimodal and tethered, and the environment is non-immersive (projected onto a screen). Our future games (some of which are already in the works) will include multi-modal biometric inputs. By employing ECG (heart rate), EMG (muscular movement), EEG (brainwaves), respiration, temperature, and several other biological signs, we hope to completely characterize the players' physiological state. In addition to using pure biological signals, we are looking into capturing and characterizing behavior-based input. We are set to begin construction of a dual camera system for gesture and posture recognition and have ongoing work into determining emotion by facial recognition and analysis.

At the moment, all of our sensors are wired to their respective amplifiers. We are currently working on a group of wireless biosensors with on-board Analog to Digital converters. This has multiple benefits. Most importantly, the interface will be far less intrusive and the user will be free to act in a natural way. In addition, the lack of wires will make gesture and facial recognition markedly simplified. Finally, wireless sensors will help us eliminate the induced 50Hz noise associated with wires. This, along with an advanced combination of Digital Signal Processing, Wavelet analysis, and mathematical theory, will hopefully allow us to eliminate most of the electrical noise which plagues sensitive measurements like EEG. We are also in the process of developing compression and filtration mechanism that are heavily optimized for biometric data.

Finally, we intend to make our future games fully immersive. As mentioned previously, a major factor in the effectiveness of biofeedback is the attention and interest of the user. Controlling more of the user's environment leaves less room for distractions and guarantees a higher level of attention. In addition, we interpret the outside world through our senses and this has a significant effect on our personal internal experience. Therefore, more command over a person's sensory environment also leads to greater influence on a person's state. Currently, our game is projected on a screen and the sound comes from speakers, allowing many ambient distractions. In the future, we are planning on building a special room so that we can control a person's sensory input as well as we can characterize their biometric output. Ambient light and noise, temperature, airflow, and even floor motion are some of the inputs that will fall under our control.

These changes, combined with a more "intelligent" environment, will create a structure which can be easily modified to accommodate many situations. As mention before, traditional biofeedback has many therapeutic uses and these can be enhanced by affective feedback. In addition, affective feedback does not need to encase traditional biofeedback in order to work. A computer with the ability to select and learn the environments that create different bio-states in an individuals has many therapeutic uses. For example, a recent University of Washington study found that burn victims who are outfitted with virtual reality equipment during painful procedures experience reduced pain sensation.[9] An environment that adapts to maintain the maximum level of immersion for each individual patient would be more effective than a static one. In addition, a responsive environment could be used to stimulate coma patients or help treat a person with autism. Recently, researchers at the University of Tübingen created a system that allowed a patient with Locked-In Syndrome to write a letter by selecting a letter of the alphabet with his brain waves.[10] These patients can communicate and be affected by the outside world, but they need a smart environment to do so.

CONCLUSIONS:

We have introduced the concept of affective feedback through a simple but profound idea – the 'relax to win' paradigm. The applications of this idea are extensive, from enhancing traditional biofeedback to using intelligent computers to select environments that positively affect the state of the user.

The forthcoming ubiquity of computation will demand new forms of input for various applications, especially computer games. Small, inexpensive, wireless, multi-modal biosensors will provide a much-needed functionality boost to everything from office applications to medical treatment.

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[1] This is the basis of neurofeedback – for a overview see: **Evans and Abarbanel. Introduction to Quantitative EEG and Neurofeedback. San Diego: Academic Press, 1999.**

[2] **Lubar, Joel F. Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. Biofeedback & Self Regulation, 1991 Sep, v16 (n3):201-225.**

[3] **Peniston, Eugene G.; Kulkosky, Paul J. a-j Brainwave training and b-endorphin levels in alcoholics. Alcoholism: Clinical & Experimental Research, 1989 Apr, v13 (n2):271-279**

[4] **Picard, Rosalind. Affective Computing. Cambridge: M.I.T. Press, 1998.**

[5] See **http://www.hitl.washington.edu/projects/burn/**

[6] One of the fundamental factors in the effectiveness of operant learning is the motivation the subject, which is based on the "value" of the reward. For a specific example in biofeedback, see: **http://mentalhealth.about.com/library/weekly/aa101600a.htm**

[7] See **Peek, Charles. "A Primer in Biofeedback Instrumentation" in Biofeedback: A Practitioner's Guide. New York: The Guilford Press, 1995, p.75-94.**

[8] Ibid

[9] See **http://www.hitl.washington.edu/projects/burn/**

[10] **Birbaumer et al. A Spelling Device for the Paralysed. Nature, 1999, March. v. 398: pages 297-298.**