Affective Feedback

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Introduction

Throughout each day, a person’s mental state can seamlessly change from groggy to aware, relaxed to agitated, or happy to sad. These changes have a profound effect on the way that people interact with themselves and the world, and yet, many people feel that they do not have control over their own internal state. From Attention Deficit Disorder (ADD) patients who cannot focus, to depressed people who cannot escape dark moods, to many people who have a difficult time relaxing – the inability to have self control over internal states is extensive across society. There are many ways for a person to positively affect their mental state, from taking drugs to going to the movies. These are only temporary measures and in the case of drugs often have negative side effects. What if there was a more controlled, predicable, and long-term way to help people reach specific mental states?

Affective Feedback is the process of using technology to help people achieve and maintain specific internal states. Essentially, we are trying to create immersive systems that encourage people to reach a specific state, such as relaxation or concentration, and "teach" them how to control it. This turns out to have therapeutic use as a significant number of disorders are linked to a patient's natural tendency towards certain particular destructive internal states. For example, a child with attention deficit disorder, who has a tendency towards an unfocused state, can use the system to learn how to maintain a concentrated state. Another example could be a person prone to depression learning how to maintain a more elevated state of mind.

How is this accomplished?

We first need the technology to create sensory immersive environments that engage and captivate the user. We then need ways and means to measure the affect of these sensory immersive environments. If we allow the technology to experiment with different sensory experiences, and to record relevant affect we have created an affective feedback system. If the goal is to help a person reach and maintain a specific internal state, the first step is to identify the factors that can cause changes in a person's state over time. This is the experimental phase. The second step is to associate particular internal states with sensory experiences. The final step is to identify comparatively positive states of mind according to that user and facilitate the user maintaining these states. This is Affective feedback. For example a person listening to their favourite piece of music whilst relaxing is in an entirely different mental state when subjected to music they don't like. If the environment was intelligent enough to "know" this state, then it could select appropriate music to relax a person. Another example of this would be an environment reminding a person to stay actively focusing on positive, relaxing thoughts and breathing deeply to cause a more “relaxed” internal state. These states are brought about by external environmental factors facilitating the changing of internal states.

How could a system “harness” the natural power of both conscious self-control and the external environment to “help” the user reach and maintain a specific internal state? First, it has been shown that people’s innate ability to control their own internal state can be refined through a process known as biofeedback [25]. However, this process is very tedious. The first part of this chapter will discuss biofeedback and show various ways that it can be improved. “Enhanced” biofeedback is the key to unlocking the potential of self-control of one’s internal state and is the first step to affective feedback. The second part to affective feedback is using the power of the environment to directly affect a person’s internal state. This will be discussed in the second part of the chapter. In its “static” form, this simply entails presenting the user with visual and auditory stimuli that invoke the appropriate internal state. The more advanced “dynamic” form involves a system that actually learns which environmental factors cause different internal states, and therefore is able to intelligently pick the appropriate stimuli to create a specific state for each unique user.

We have created two immersive video games which help the user reach and maintain both relaxed and concentrated states. The games are designed with a structure which demonstrates the real-world application of affective feedback.

Biofeedback Vs. Affective feedback

The first key to affective feedback is to utilise the user’s innate power to consciously control an aspect of their physiological state. This control could be enhanced through the process of biofeedback. However traditional biofeedback is a long, boring and uncomfortable process. This section of the chapter discusses traditional biofeedback and the multiple ways that it can be improved to make it more effective and efficient. Suppose that a person is learning how to play darts for the first time. If their first few tosses don't make it to the board or land far left of the target, he will react by throwing the dart faster and more to the right on the next toss. After multiple throws, the person will slowly gain a "feel" for how the subtleties of their actions effect the final position of the dart on the board. Intuitively, the key part of this process is receiving "feedback" evaluating the result in relation to the original goal. For example, if the room were completely dark, the person would never perceive the result of their efforts and would soon give up on trying to learn to play darts. In a basic form, this is referred to as "operant learning": someone throws the dart, receives feedback from the result, and changes their next throw accordingly. It is important to note that the operant learning model requires some sense of motivation – a person who does not care about darts will not learn as effectively as a person who is passionate about the sport.

Now, imagine a person trying to learn how to control the blood flow to their hand. Generally, people have some innate sense of the state of warmth in their hands, but the gradient of differentiation between levels (cold, normal, hot) is very large. In other words, the quality of feedback is poor. This is similar to playing darts in the dark and only being able to hear if the dart hits the board or the wall. It is possible to learn to hit the board, just as it is possible to learn that focusing thoughts on the hand for an extended period will warm it up. However, as the quality of feedback is directly linked to the level of learning, it is impossible to gain more subtle control without better feedback.

Clearly, feedback is not the only issue. A sense of causation between the action and the system you are trying to affect is necessary: receiving feedback concerning moon cycles will not give a person control of the moon. In fact, for many decades, it was assumed that the autonomic nervous system (ANS), which controls homeostatic control systems in the body such as heartbeat, was not under voluntary control. This has proved to be untrue [38]. Medical science and technology have advanced to provide new methods of displaying biological states (such as real-time blood pressure and body temperature). With more refined feedback, it is clear a person *can* control these previously considered involuntary biological functions [27,29,35].

This process is known as biofeedback, and has been used to gain conscious control over many aspects of the ANS. For example, Dewan in 1971 [37] showed the possibility of gaining control of brainwaves to send Morse code messages by consciously oscillating certain brainwaves frequencies. There are many other examples of conscious control of brainwaves, heart rate, specific sections of muscles, and blood flow, among others [4,5,39,40,43].

Is there any practical use in learning how to control the ANS, or is it simply a skill like throwing darts? It turns out that biofeedback has significant therapeutic uses and is employed for that purpose in many fields. Controlling blood flow is a method of helping people with Raynaud's Disease (see website No. 3 in references), which is characterized by poor circulation to extremities. Gaining muscle control through biofeedback is a preferred therapy for treating incontinence [39,40,41]. Similarly, musculoskeletal biofeedback is consistently used for physical therapy [42].

However, the most interesting, and perhaps most controversial, form of biofeedback is known as neurofeedback and involves learning how to control one's brain-state. But how does one "display" a "brain-state" in order to present a person with accurate real-time feedback? We will leave this problem until the next section of the chapter. For now, it is only important to note that it *is* possible to provide very limited feedback regarding brain events with an electroencephalogram (EEG). Using this information, people can learn how to increase the relative amplitude of certain frequencies of brainwaves (which, in broad categories, map to brain-states such as concentration) in different topical areas of the brain. This is not easy and requires a significant number of training sessions to master [3,5,6]. However, after a sufficient number of training sessions, it is believed that the long-term structure of the brain actually changes in a way that makes this brain-state more possible in the future [38]. As multiple disorders, such as epilepsy [6-22] and depression [1,2,3,4,5] have been linked to time-reliant irregularities in certain frequencies in specific areas of the brain, biofeedback can be used to treat these problems. For example, training children to increase high frequency brain waves, which roughly map to a state of concentration, has been shown to be effective treatment for attention deficit disorder [23-35].

While it has been proven that people can use biofeedback to gain control of functions that were previously thought to be out of conscious control, there are serious limitations. In the early stages of biofeedback in the 1970s, the over-excitement and non-scientific claims of many practitioners tarnished the reputation of the discipline to the point that it is only recovering today. The simple lesson is that denying the problems with biofeedback is more dangerous than exposing them. As with the examples of playing darts or controlling heartbeat, the learning process is severely dependant on the quality of feedback. This is not as much of a problem for monitoring a simple, low-noise bio-signal such as a heartbeat. However, a signal such as an EEG is weak and plagued with noise that reduces the quality of the feedback. Additionally, measuring bio-signals often involves a large amount of expensive equipment consisting of electrodes and wires, which must be directly applied to the person's body. This reduces the number of people with access to the technology as well as making the process uncomfortable for the user. Motivation is also a huge issue, especially for children, as the training period is long and demanding. If the person is not completely behind the process, effective biofeedback is very difficult. Finally, as with any skill, humans are limited by their own personal capacity. Just as a person can only play darts so well, a person can only gain so much control of their ANS.

While the last problem is inescapable, the first three can be partially solved if the biofeedback system is improved. The first step towards affective feedback is to make multiple enhancements to traditional biofeedback.

As the general idea of feedback is a necessity, the key is to "house" the feedback in a more effective environment. This section of the paper will discuss ways to (1) improve traditional biofeedback directly and (2) create a framework that increases motivation in the user.

(1) Improving Biofeedback Directly - As mentioned earlier, two major issues confronting biofeedback are the relatively poor quality of some bio-signals (and hence

the feedback) and the fact that the equipment is not wireless. Unless these problems are addressed, there is little possibility of effective traditional biofeedback. Therefore, solving these problems through the use of non-invasive, affordable wireless sensors and advanced signal processing is a necessary, but not sufficient, step towards achieving affective feedback. Another important step toward affective feedback is the use of multiple bio-signals, a “multi-modal approach.”

(a) Wireless, Affordable Sensors – Currently, professional equipment to measure bio-states for research purposes, such as the Biopac© System, cost upwards of $11,000 (2001 pricelist). Dedicated biofeedback machines designed for a specific training system on a PC, such as the WaveRider Pro, cost about $1500 (2001 pricelist) (Website No. 5). This is significant expenditure for home use or even for a professional practice. In addition, the equipment is generally not wireless, requires substantial effort to use, and is uncomfortable.

    For our last two projects, we have developed custom amplifiers and biosensors to circumvent these problems. Our goal was to design affordable, comfortable, small, systems that produced accurate and clean bio-signals. Some of the problems that we tackled during the design phase included power consumption, weight, and movement artefact. The final product was custom GSR and EEG sensors and amplifiers. We are working to make the system wireless.

(b) Using Signal Processing – Extracting pertinent information from a bio-signal demands complex signal processing. By their very nature bio-signals are nonstationary and so their frequency characteristics change with time. This means that techniques like Fourier analysis need to be modified to account for issues like drift, noise and information in the signals changing form over time. In addition to provide effective feedback information, it is necessary to display an accurate representation of the current state of the system being influenced. Therefore, one of the first issues in biofeedback is finding a concrete way of displaying systems that are abstract (like brain state) or directly immeasurable (like sweat gland activity). Quasi real-time feedback is also necessary because as the time lag gets greater, the mind has a harder time deciphering which actions associate with the system's reactions. Novel real time signal processing is therefore an essential part of affective feedback.

(c) Multi-Modal Approach - If a user is trying to learn how to increase "alpha" waves in the brain, the feedback information should clearly reflect the level of "alpha" waves. But, what if one is trying to promote an abstract mental state, such as "relaxation?" Alpha waves are a useful measure of mental inactivity that can be associated with "relaxation," whereas heartbeat variability and galvanic skin response can have characteristics associated with motor relaxation. While these signals are correlated, they still contain independent information. Therefore, it is reasonable to assume that they all reflect certain aspects of "relaxation." If this is the case, the measure (and feedback) of "relaxation" should somehow reflect a combination of these signals. In other words, it is always helpful to gather as much meaningful information as possible.

This is the logic behind a so-called “multi-modal” approach – the use of multiple bio-signals for feedback. This is an important method for encouraging any abstract mental state, and is crucial to the concept of affective feedback.

(2) Improving Motivation - Operant learning relies heavily on the user’s desire to determine the relation between their actions and its effect on the outside system. In fact, user motivation is usually one of the key reasons that biofeedback training fails, especially with children. It is not easy to convince anyone, let alone a child, to put full effort into a time-consuming, difficult task with abstract goals. This is where affective feedback comes in – to house the training in an environment that provides the motivation necessary to succeed.

Originally, feedback was simply a dot on a screen, which only moved vertically to demonstrate the level of achievement [37]. Clearly, a person must be very focused on the end goal of controlling their bio-state in order to endure hours of staring at a dot! As it became obvious that this was not compelling enough for children (or most adults), practitioners headed in the direction of affective feedback by housing the biofeedback in a simple game. An example is a commonly used modified Pac-man game, in which the Pac-man gobbles more dots as the desired bio-signals are produced. The problem is that these games are essentially just a graphically enhanced representation of the “dot,” which soon loses its novelty. Nonetheless, the games are more effective than traditional biofeedback and see widespread use. Affective feedback is the continuation of this trend towards a situation where people are excited to participate in the experience of biofeedback without having to focus on the long-term goals of bio-signal control.

There are a few ways this is accomplished:

(a) Augmented Reality to Immerse – A student who drifts off or loses interest during a lecture will not learn as much as a student who is paying complete attention. Good advertisers, teachers, and preachers keep this in mind when trying to hold the attention of their audience. Two complementary ways to achieve this goal are to make the message itself more interesting and to remove all possible environmental factors that might create a distraction.

When watching a movie in the theatre, it is very difficult not to pay attention, even if the movie is terrible. This is due to the fact that the auditory and visual display of the movie overwhelms the senses: the movie is the entire environmental experience and it is nearly impossible to avoid paying attention to it. Therefore, one way to increase the attention of the user (and block distractions) is to completely control their sensory input, "immersing" them in a augmented world.

Clearly, this is not enough to guarantee interest as the user can always turn their mind inward. The next step is making the environment more intriguing, so that the person has an interest in paying attention to it. While the user will never forget that they are in a "false" world, the new environment will command more attention and have a greater affect on their internal state as their "presence" (belief in the world) increases. How much realism is necessary to completely draw the attention of the user? It turns out that, if a person is completely immersed, very simple scenes can draw significant attention resources [44].

(b) Gaming Environment and Storyline – Evolutionary psychologists believe that humans (as well as some other primates) have a natural inclination to play “games” because they allow for the practice and perfection of skills in a relatively non-threatening environment [45]. Therefore, using a game is an optimal way to teach a skill as it creates natural motivation and interest in the user. Generally, success within the game provides the primary reward, while secondary skills are gladly learned as a bi-product. Note that games can be used to train relatively arbitrary skills: children are excited to learn how to press buttons in a certain order very quickly if connected with success in an interesting computer game. These enhancements make biofeedback more comfortable, enjoyable, and effective. They do not require the user to have an interest in succeeding in the biofeedback process – only that they enjoy playing an immersive game. Over time, the user will be able to control an aspect of their physiological state, which is the first step to affective feedback.

Environmental conditions affecting internal state

People are not as consistent as they would like to believe. While every person does have a set of tendencies to act and react in certain ways, personality is somewhat plastic. The same person can be competitive or cooperative, relaxed or stressed, and generous or stingy depending on their environment. Therefore, the immediate environment can play a huge role in the way that a person thinks and who they “are” in that moment. This suggests that a person's environment can be manipulated to directly affect their internal state. Architects and designers for example, have known about this for a long time: places where we live and work are specifically designed to elicit a generally positive emotion in the user.

However, while we use this principle everyday without recognition, it is an extremely powerful idea when combined with the application of biofeedback. In its "static" form, this involves using the framework which houses the biofeedback to directly influence the bio-state of the user and hence the effectiveness of the training. This type of affective biofeedback is "static" because the environmental framework does not change for different users. Alternatively, the more advanced "dynamic" affective feedback involves the environmental controller actually "learning" which situations bring out different bio-states in each individual user and using that knowledge to promote the desired state.

Traditional biofeedback can be seen as an operant learning loop between the user and the computer – the person acts, notices changes in the display based on their bio-signs, and reacts accordingly. Dynamic affective feedback introduces a new loop – the computer acts by manipulating the user's environment, recording the changes in the user, and reacting appropriately.

It is important to note that this new loop can be implemented without biofeedback. If the user does not want to actively participate in the feedback process, the computer can work in the background to subtly change the user's environment and learn its effects on their state. Over time, the computer will have the power to proactively affect the internal state of the user in a predicable way. This technology can help the user reach a chosen internal state without requiring significant effort from the user.

A cloudy and rainy day has a much different effect on a person than a clear and sunny day. In general, simply displaying warm colours instead of cold colours can set different moods. The effect is not solely colour-based: Large and open rooms create a different “feel” to claustrophobic ones. A simple and uncluttered scene effects people differently than cluttered, gaudy setting. After analysis, it is clear that virtually everything human-made, from homes to products to clothes, is designed to create specific sensations in the user. This power can be captured and used in a constructive way to help people achieve and maintain different mental states.

Static affective feedback (SAF) is essentially the marriage of biofeedback with multiple technologies shown to affect the user’s internal state. While the connections between technologies are original, the individual technologies are not. However, dynamic affective feedback (DAF) is a radical new method that will drastically change the way that computers react to people.

Technology has reached the point that computers can begin to receive information from their users in a more profound way than by using a keyboard. There is, in fact, a new trend in computing to create computers with the ability to recognize and react to the user’s emotional state [45]. However, most applications of this concept involve using a simple algorithm to link the computer with the user: the computer determines that the user is in state “X” and therefore does “Y.” However, why not enable the computer to be an active participant in the process?

Static affective feedback relies on the fact that different scenes create different moods. However, it ignores the fact that a specific scene can have a different effect on each individual person. A simple look at how people decorate their homes suggests that people have unique feelings associated with different environments. Therefore, a way to improve on static affective feedback would be to determine how different environments effect each individual, rather than assuming environments have the same effect on all people. For example, if the computer is trying to “help” put the user in a concentrated state, what environment should it use? Take a look at where people study - Some people feel more focused in an open and busy environment, like a café, while others prefer a quite and closed setting, like a library. The only way the computer can determine the type of its user is by testing out different environments and seeing how the person reacts.

In the biofeedback process, the person receives information about their bio-state from the computer and slowly learns how to control it, by associating internal changes with changes of the environment. In DAF, the computer receives information about the person’s bio-state from the sensors and slowly learns how to affect it, by associating its environmental changes with bio-changes in person. Although it is convenient to see this as the addition of a new separate feedback loop, it is clear the loops are not independant.

What parts of the environment can the computer manipulate to learn how to affect the user’s internal state? Essentially, most of the components mentioned in the SAF section can be dynamically manipulated with appropriate effort. In theory, it is entirely possible to change the underlying framework, such as the characters and fundamental storyline, dynamically.

Interfacing the virtual world

The virtual world has many advantages for creating an immersive environment. One of the greatest advantages is that all visual and auditory parameters can be directly controlled and more significantly, recorded. The fact that all of the sensory information can be controlled, enables psychologists and psychotherapists alike to produce a sensory state that has direct influence on the inner state of the person. This can be independent of biofeedback. For example, an extremely simple virtual scenario called "SpiderWorld" (see figure 1) is used to treat arachnophobia by helping patients to confront their fear in a safe environment [46,48,50]. The world consists of a very basic modelled kitchen with a less-than-realistic spider crawling around. Even though it is very basic, subjects are very attentive and respond as if the scene was real.

Figure 1: Representation of the spider world virtual environment.

However does this increase in attention reduce the effect of outside distractions? Researchers working at the University of Washington found that when burn victims were immersed in a “Snow World” (see figure 2), the pain of dressing the wounds was lessened [47,49]. Why? “Being drawn into another world drains a lot of attentional resources, leaving less attention available to process pain signals.”

Figure 2: Representation of Snow World in the virtual environment.

Controlling the user's entire auditory and visual sensory input focuses their attention to the point of distracting the person from pain. This shows that the use of immersive reality not only acts to captivate the user, but also to reduce possible environmental distractions. It is with this in mind that the Mindgames group has produced two games in particular to examine the validity of this concept.

"Relax-to-Win" - a competitive two player racing game. Each player controls an animated 3-d dragon in a virtual racetrack environment where the goal is to cross the finish line first (see figure 3). 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 (GSR), 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. The game places users in a competitive environment not only to provide motivation, but to teach them how to relax in a stress-inducing situation.

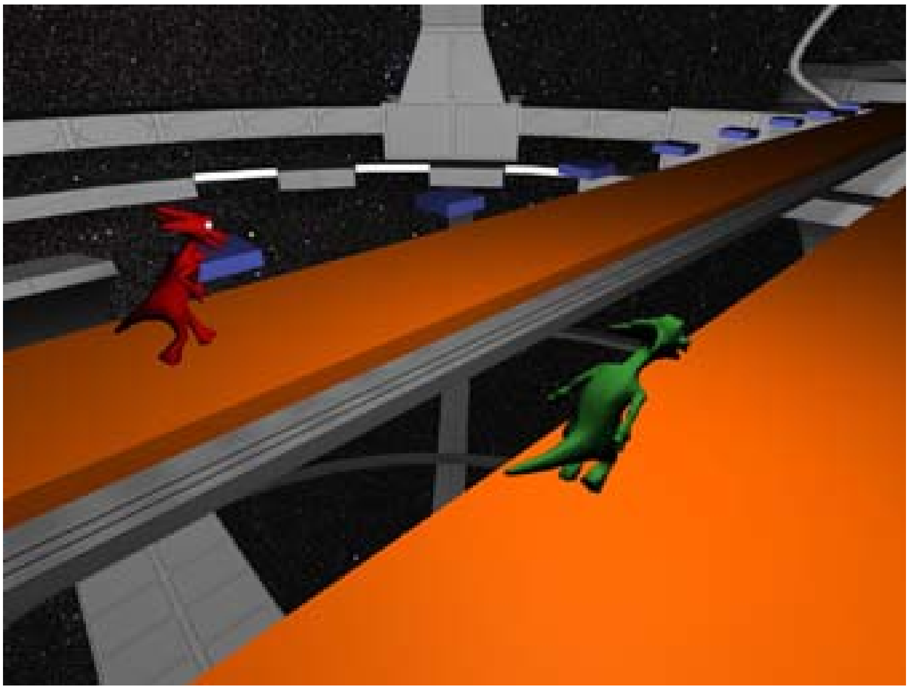

Figure 3: Screen Shot from “Relax to Win”

“Brainchild” - Brainchild is a biometrically-controlled modular computer game which teaches the user how to gain control over various bio-signals. The game immerses the player in a compelling fantasy storyline using professional-quality sound and video (see figure 4). The user is taught how to train their “magic” (biometric) skills by a mentor character who leads the user through the story and process. For example, the player’s skill of relaxation is mapped to the “magical” skill of telekinesis. In the first level of the game, the player is brought to a lock mechanism that they must open with their mind. The mentor “helps” the user to relax using interactive dialogue that changes in response to perceived levels of relaxation as measured by a combination of GSR and alpha wave content, and the lock begins to open as the person relaxes. Later in the game, if the player requires the power of telekinesis, he must again relax. Note that various elements of the game directly "help" the user reach their desired bio-state - If the user is learning how to control their relaxation level, the music, video, and dialogue will "help" put them in this state. Overall, the game provides the perfect structure to explore and experiment with the "Affective Feedback" concept.

Figure 4: Screen Shot from "Brainchild"

Summary:

In this chapter we have introduced the concept of Affective Feedback. This involves augmenting the traditional methods of Biofeedback with sensory immersion, novel signal processing, compelling game play and narrative and intelligent technology having an active role in the biofeedback loop. Biofeedback is a powerful under-utilised concept that can be used to enable and empower an individual by giving them access to information only technology can provide. It's usefulness is hampered by inappropriate technology and wild claims about what it can do. Affective feedback is a way of making better use of the power of Biofeedback and relies on an integration of available technologies and expertise which we have outlined in this chapter.

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(VR Therapy for burn victims)

(3) http://members.aol.com/raynauds/biofeed.htm

(Raynauds Disease sufferers opinion on Feedback)

(4) http://www.snr-jnt.org/NFBArch/Abstracts/walkerj1.htm

(Jonathan Walker, M.D., Neurologist, Dallas, TX, May, 1995)

(5) http://www.elixa.com/mental/wrpro.htm

(Waverider feedback hardware and software resourses)