Helping Video Games "Rewire Our Minds"

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Biofeedback-modulated video games are games that respond to physiological signals as well as mouse, joystick or game controller input; they embody the concept of improving physiological functioning by rewarding specific healthy body signals with success at playing a video game. The NASA patented biofeedback-modulated game method blends biofeedback into popular off-the-shelf video games in such a way that the games do not lose their entertainment value. This method uses physiological signals (e.g., electroencephalogram frequency band ratio) not simply to drive a biofeedback display directly, or periodically modify a task as in other systems, but to continuously modulate parameters (e.g., game character speed and mobility) of a game task in real time while the game task is being performed by other means (e.g., a game controller).

Biofeedback-modulated video games represent a new generation of computer and video game environments that train valuable mental skills beyond eye-hand coordination. These psychophysiological training technologies are poised to exploit the revolution in interactive multimedia home entertainment for the personal improvement, not just the diversion, of the user (Business Week, December 23, 1996, p. 68).

Background: Biofeedback as training method

Biofeedback is a well-established and scientifically validated method, which is used to treat a variety of health problems. It consists of placing sensors on the body to measure biological activity, and showing patients on a computer screen (typically in the form of dynamic graphs) what is going on inside their bodies. When patients are made aware of the moment-to-moment changes in their physiological activity in this way, they can learn over time to control various body functions that are usually outside of conscious control, such as heart rate, muscle tension or blood flow in the skin. Biofeedback has been used for forty years with considerable success in the treatment of various health problems, such as migraine headaches, hypertension, and muscle aches and pains.

Brainwave biofeedback, or neurofeedback, training systems provide real-time information to trainees showing them how well they are producing brainwave patterns that match a criterion pattern. Success at producing the desired changes in brain activity, as well as improvements in sustained attention, concentration and academic performance, have been reported as outcomes of neurofeedback training (Lubar, 1991). However, non-adherence to the training regimen often undermines this treatment alternative. Brainwave-modulated video games are specifically designed to overcome this drawback, incorporating engaging graphics and animation to promote adherence to training practice through entertainment appeal. One effective use of the brainwave-modulated game concept is to augment current biofeedback techniques for Attention-Deficit Disorder by providing a rewarding environment in which trainees can demonstrate and improve skills learned in conventional training.

Although scientific research has shown biofeedback to be an effective form of medical treatment for several disorders, some aspects of this treatment have made it less widely used than it could otherwise be: Biofeedback tends to be tedious, the treatment requires numerous sessions, it can

be hard to learn in the first place, and it is an expensive treatment (as it typically requires several visits to a specialized clinic).

Prior to the NASA video game biofeedback innovation, brainwave biofeedback systems delivered training in bland and minimally motivating task formats. State-of-the-art commercial brainwave biofeedback systems generally incorporate game-like graphics which are not truly games as they simply drive displayed biofeedback graphics directly with a physiological signal. Brainwave-modulated video games, in contrast, fully integrate brainwave biofeedback training into a true, dynamic video game. Specific brainwave changes are reinforced by success at playing the video game. The video game format motivates trainees to participate in and adhere to the training process. Typically, brainwave biofeedback training for Attention Deficit Disorder requires between forty (40) and sixty (60) sessions for children and sometimes fifty (50) to seventy (70) sessions for adults. The new video game training technology transforms an arduous training regimen into game playing time. The popular pastime of playing video games, considered a "social evil" by some, becomes an opportunity for developing valuable mental skills.

The video game biofeedback technology

The video game biofeedback technology developed by NASA was partly created in an effort to find a way for biofeedback to overcome all of the obstacles to its usefulness, so that it can become more widely used, easier to apply for training, and more appealing to the people it can help.

The biofeedback video game concept (patented by NASA in 1994 and patent pending 1999) evolved from a physiologically-adaptive simulator system that was developed in NASA flight deck research. In this system, brainwaves of pilots controlled the level of automation in a simulator flight deck. This "closed-loop" testing setup was used to determine what level of automation kept pilots engaged best in the flight task. It was soon realized that, given enough practice, pilots could probably turn the testing system into a training system; that is, they would learn to control their brainwaves to set the level of automation where they wanted. This becomes essentially a brainwave biofeedback training situation. It differs from conventional brainwave biofeedback in that the feedback and reward are not explicit on a display, but implicit in the subject's control of the task's difficulty with brainwaves. If the flight simulator is replaced with a video game, as it was in the spin-off technology, the system becomes an entertaining way to deliver brainwave biofeedback training. With this technology, biofeedback happens in the background as a person plays the games, and the training is therefore effortless and does not become boring.

The first research study of the video game biofeedback technology

A randomized and controlled technology concept study (Palsson et al., 2001) conducted at Eastern Virginia Medical School evaluated the effectiveness of a prototype version of a video game biofeedback training system.

Attention Deficit Disorder (ADD/ADHD) is a common disorder and was selected as the target disorder for treatment in this trial because it is the problem which has been treated most with brainwave biofeedback in the past.

The study assessed whether a prototype version of the new video game biofeedback technology developed at NASA Langley Research Center was as effective as traditional neurofeedback in treating Attention Deficit Disorder, and whether there were significant differences in its appeal as a clinical method compared to standard neurofeedback treatment.

Research study design:

The study was conducted in the Behavioral Medicine Clinic at the Eastern Virginia Medical School. Twenty-two children between the ages of 9 and 13 years who had Attention Deficit

Disorder of the hyperactive-impulsive type (the most common type of this disorder) were randomly divided into two groups of equal size. One group received standard brainwave biofeedback and the other played Sony Playstation™ video games, which were influenced by the NASA prototype biofeedback system. Children in each group came individually for 40 training sessions, typically completing two sessions a week. Each training session lasted about an hour. All the children were on short-acting medications for ADHD. The children had to be of at least normal intelligence, and have no history of affective problems or learning disabilities.

In the standard brainwave biofeedback group, the children were trained with visual feedback about their brainwave activity, in the form of dynamic graphs or animated visual shapes such as a smiling face (this is the kind of feedback commonly used in clinical training of this kind). In the video game group, children played Sony Playstation™ games such as car racing games, skateboarding games, or adventure games such as Spyro the Dragon©. These games were modulated by the NASA equipment so they behaved differently according to the player's brain activity from moment to moment.

In traditional brainwave or electroencephalogram (EEG) biofeedback a child with ADD may be tasked with trying to make one colored bar go higher (by producing more fast brain waves) and another go lower (by producing less slow brain waves). Some existing software also allows them to play simple video games that reinforce the faster brain 'beta' waves. The NASA video game technology works with off-the-shelf video games. When players produce faster brain waves - beta waves - the game controller or joystick for the video game is more responsive, and they can better control the characters or objects on the screen. When players use slower brain waves - theta waves - the game controller is more sluggish.

Brain activity was measured in both groups with a brainwave sensor (EEG sensor) placed on the top of the head in a standard (Cz) location (with a reference electrode and ground attached to the earlobes).

Brainwave biofeedback focuses on training people to change the functioning of their brain by showing them the strength of different brainwave frequency bands, and encouraging them to systematically make some brainwave frequencies stronger and others weaker. In both groups, the training was aimed at reducing the strength of slow brainwave activity in the theta (4-7 Hz) and alpha (8-12 Hz) brainwave frequency range, and amplifying faster brainwaves in the SMR (13-15 Hz) and low beta (15-21 Hz) ranges.

Before and after treatment, several neuropsychological tests, behavioral measures, physical motion sensors (to measure hyperactivity of movement directly), and quantitative brain activity (QEEG) recordings were used to assess the effects of the treatment. Parents also completed detailed standardized behavioral questionnaires about their children before treatment, after every ten treatment sessions, and after the end of treatment. Parents and children furthermore completed at the end of the treatment rating scales of overall changes in the ADHD problem and their satisfaction with the treatment and with the results.

Results and conclusions:

Both the experimental video game biofeedback technology and the standard brainwave biofeedback training had a substantial therapeutic effect on ADD symptoms, based on consistent and statistically significant changes across several key outcome variables. Both groups improved substantially and about equally in their inattention and hyperactivity problems, which are the central symptoms of the disorder. These findings are outlined online at http://chem.larc.nasa.gov/AAPBvideogame.pdf.

The main group difference seen in the results were that both parents and the children in the video game group rated significantly higher how much the children enjoyed coming to the sessions. The

children in the video game group gave the treatment an average enjoyability rating of 9.5 on a ten point scale, which is statistically significantly above the 7.8 average rating for the control group.

The parents in the video game group estimated that on average their children's symptoms had improved by 65 percent after the course of treatment, compared to an average estimate of only 48 percent by the parents of the children in the standard brainwave biofeedback group.

Trends on pre-post quantitative EEG change maps indicated that the video game training may have advantages in creating more quantitative EEG effect in the therapeutic direction.

It seems clear from our study that this way of blending biofeedback into video games is as effective at improving the symptoms of attention deficit disorder as standard brainwave biofeedback -- but is much more enjoyable and easier for the children treated. The video game biofeedback technology, as implemented in the NASA prototype tested, produces equivalent results to standard neurofeedback in effects on ADHD problems. Both the video game and standard neurofeedback improve the functioning of children with ADHD substantially in addition to the benefits of medication. The video game technology provides advantages over standard neurofeedback treatment in terms of enjoyability for the children and positive parent perception, and possibly has stronger quantitative post-treatment effects on EEG.

Discussion

The video game biofeedback method is inherently motivating, and thus keeps trainees on task continually. The method blends sophisticated neurofeedback (or biofeedback) training into popular entertainment in such subtle ways that the entertainment value is not lost and EEG biofeedback training is no longer a chore but a treat. This approach allows individuals to select the games that they like best, making sure that the games stay current and are suitable for each person's gender and developmental level. The technology can be used largely without clinician involvement or effort – making group treatment or properly arranged home use easy. It is furthermore an inexpensive technology, as game software does not have to be specially written for EEG biofeedback.

The modulation method employed in this study explicitly sets up brainwave performance criteria, in addition to the usual hand-eye coordination criteria, for success in playing the video game. For producing particular brainwave patterns, the player is explicitly rewarded by improved capability and performance in playing the game. As a consequence, production of these brainwave patterns is reinforced; that is, the patterns are more likely to occur as the game progresses. As shown in the study, improved cognitive skills and behavior accompany these brainwave changes. Whether the training produces lasting changes in brainwave activity, and/or improvements in the trainee's ability to recruit these changes when needed, are questions for further research. The reinforcement principle involved in this process is known as the Premack prepotent principle, which is stated: "A high probability behavior may be used as the reinforcer for a low probability behavior" (Premack, 1965). A high probability behavior may be understood as that activity in which an individual will engage in the given situation, if unconstrained (for example, video game playing.) The "low probability behavior" in this case is production of non-ADD brainwave patterns.

While the effects of brainwave-modulated video game playing on behavior and brain activity have been demonstrated in this study, the effects of ordinary unmodulated video game playing on the brain and behavior have yet to be established.

Although reinforcement contingencies for particular psychophysiological responses and states are not explicitly programmed into regular video games, are there, nevertheless, certain mental states and the accompanying brain and autonomic responses that video game players are receiving a great deal of practice in producing? And what might some of these responses be?

Poole (2000, p. 168) reports that many people describe certain video game experiences " ... as a 'Zen' experience. This is understood to be shorthand for a kind of high-speed meditation, an intense absorption in which the dynamic form of successful play becomes beautiful and satisfying." Poole characterizes these experiences as examples of the "flow" concept introduced by Csikszentmihalyi (1990). Bryce and Rutter (2001a) are investigating "psychological presence in public gaming arenas ... by the use of the optimal experience or the flow framework. ... Preliminary research suggests that the psychological experience of gaming is consistent with the dimensions of the flow experience as outlined by Csikszentmihalyi. [...] Gamers typically described 'being in the zone' or 'in the flow' of the game. The psychological experience of flow during competitive or non-competitive gaming form the basis of the psychological presence of gamers within the game and provides a useful framework investigating differences of the experience of gaming between different game genres and context of play."

An article in the UK national newspaper "The Sunday Times" (July 22, 2001) stated that work done by Bryce and Rutter of the Digiplay Initiative supported the claim that "computer games are giving a generation of young Britons a level of co-ordination and powers of concentration equivalent to those observed in top-level athletes, a government-funded study has shown" (Leake, 2001). Although this report at first seemed to offer a finding concerning the effects of unmodulated video game playing on the brain and behavior, the points were refuted by Bryce and Rutter on their website:

"The following quotation was misattributed to Jo Bryce: 'People who play games regularly seem to develop a mental state that we have seen before only in serious athletes or professionals such as astronauts, whose life depends on concentration and co-ordination,' [...] 'Their minds and bodies work together much better than those of most other people.' We did not state such effects and it would appear that [the reporter] has misunderstood the rationale and results of our research. The research conducted seeks to examine how the psychological experience of gaming compares with that of other leisure activities, of which sporting activities are one example. Our research seeks to investigate the experience of gaming and to investigate the reasons why this activity is such a popular leisure pastime. We do not seek to investigate the psychological or educational consequences of computer gaming" (Bryce and Rutter, 2001b).

Poole qualifies the flow concept for application to video game playing: "Now what about the 'feelings of complete control' that are said to accompany a flow experience? I think there is, again, something wrong with this way of putting it. [...] The point is that the pianist begins really to play the music, and thereby enters into a 'flow' state, at precisely the stage when she is no longer consciously controlling the individual movements of the fingers. [...] A reduction in self-consciousness is naturally pursuant upon the observation that my critical 'self' is no longer controlling my mechanical finger movements, so that I feel to that extent absorbed into the music itself. And exactly the same process operates in videogames" (Poole, 2000, pp. 169, 170).

In an August 19, 2001 article in the UK newspaper website Guardian Unlimited Observer entitled, "Computer games stunt teen brains", it is reported that "Professor Ryuta Kawashima and his team at Tohoku University in Japan [...] found that the computer game only stimulated activity in the parts of the brain associated with vision and movement. In contrast, arithmetic stimulated brain activity in both the left and right hemispheres of the frontal lobe - the area of the brain most associated with learning, memory and emotion" (McVeigh, 2001). This finding of relatively less frontal activity with video game playing is consistent with the suspension of critical, analytical thought that is associated with absorbing experiences.

In *Our Sweetest Hours: Recreation and the Mental State of Absorption*, Quarrick (1989) puts it this way: "It might seem incongruous that some sports can be played more effectively in the absorbed state. [...] In fact, it seems that those sports, where performance depends on split-second decisions, cannot even be performed in everyday consciousness" (Quarrick, 1989, p.

160). "It is likely that in sport, as an art, the one who dabbles has the lesser enjoyment. [...] on the other hand, the individual who cultivates a sport over a long period of time is likely to approach the recreational ideal of total involvement. As skills are perfected, actions become effortless and unself-conscious so that total attention can be given to the sport. As in the case of art, the cultivation of sport starts out as work, but with increased mastery, there is a greater capacity to move harmoniously with the sport. This makes it intensely absorbing and enjoyable" (Quarrick, 1989, p. 153). "If it occurs at all, the flow experience develops after the athlete has reached a peak of coordinated movement, and feels carried along by the rhythm, tempo, and challenge of the sport. It is only then, on the crest of harmonious action, that he might coast into an absorbed spell. Thus absorption is not a prerequisite for sport activity as it is for story enjoyment or aesthetic experience. Absorption is a by-product; it is the cream of sport" (Quarrick, 1989, p. 157).

"It is also interesting to note that the most significant recreational developments of the twentieth-century have been in the direction of creating diversions that are ever more absorbing" (Quarrick, 1989, p. 8.

In their introduction to the phenomenon of hypnotic trance, Spiegel and Spiegel could well be describing the mental state experience that is often invoked by video game playing:
"No absolute dividing line exists between hypnotic and nonhypnotic alterations in consciousness, but altered, dissociated or hypnotic-like experiences clearly occur in everyday life and provide a useful backdrop for understanding the hypnotic experience. [...]
Intense concentration in either work or play maximizes focal awareness so that events may occur around a person and be entirely outside his awareness; whereas ordinarily the signals from the periphery would be consciously perceived" (Spiegel and Spiegel, pp. 11, 12).

Do video game play-induced states offer an appealing respite similar to that provided by other consciousness altering exercises, such as meditation and deep relaxation--practices often prescribed by therapists for stress sufferers?

"Hypnosis represents an ASC [altered state of consciousness] that is similar to other ASCs, which are beneficial in themselves. ASCs promote physiological changes that are the opposite of the stress response and may in fact be our innate way of preventing the detrimental effects of this response, which is biologically programmed into all of us. ASCs also increase the effectiveness of suggestions and imagery.
Tart (1977) believed that entering into an ASC allows shifts in perspective that facilitate a different view of the universe. He envisioned a science of ASCs that would parallel our present science associated with the waking, alert state. As people became proficient at moving from one state into another, perhaps the USC [usual state of consciousness] will expand to include more of what we now think of as ASCs, making us richer both in personality and in understanding" (Pratt, et al., p. 41).

Weil (1986) proposes that altered states have a universal allure: "We seem to be born with a drive to experience episodes of altered consciousness. This drive expresses itself at very early ages in all children in activities designed to cause loss or major disturbance of ordinary awareness" (Weil, 1986, p. 23).

Does part of the attractiveness of video game playing lie in the opportunity to experience episodes of altered consciousness?

Conventional biofeedback has proven to be an effective way of enhancing the benefits of therapeutic state experiences. Biofeedback-modulated video games that require players to also exhibit the physiological signs of relaxation in order to succeed offer an enhancement of the video game escape from stress.

What are some other possibilities for the application of physiological modulation in video games to enhance the enjoyment as well as the lasting health and performance benefits of video game playing?

Norris (1986, p. 10, 12) points out "Top athletes [...] make excelling in their chosen type of psychophysiological control of the craniospinal system and striate muscles the major focus of their efforts. Here in the West, we value objectivism, material things, and have turned our attention outward toward controlling the external world. In the East, it has been quite different; the orientation of science and society values subjectivism and numinal experiences, and they have turned their attention inward, toward control of the internal world. Therefore, their champion 'acrobats' are those individuals who can assert and demonstrate control over autonomic and other internal processes. [...] in India, they have a sort of autonomic Olympics, where yogis and adepts come from far and wide to demonstrate their prowess at such things..." Physiologically-modulated video games may offer the opportunity for a similar type of competitive sport.

Training systems based on the biofeedback-modulated video game concept are applicable to pilot attention skill training and training of operators of other complex systems, such as nuclear power plants, that require sustained operator attention. Training efficiency can be improved, and the training fosters a higher level of operator readiness.

From a survey of errors of omission in the Aviation Safety Reporting System (ASRS), Pope & Bogart (1992) delineate "... a progression from active monitoring through focused monitoring to excessive absorption. [...] Attentional focusing becomes hazardous when it is unintentional and becomes excessive absorption. Excessive absorption results in an individual being oblivious to all but a few elements in the present environment; reorienting to a wider awareness would be effortful and time consuming. Descriptions that refer to this state of absorption in the ASRS narratives include ' hypnotized,' ' become focused,' and ' totally absorbed our concentration and forgot the big picture.' The cognitive experience associated with this state has been termed attentional 'tunneling' and 'channelization' (Lee, 1990), and is similar in result to the attentional narrowing reported in certain high stress situations (Endsley, 1989). Whereas the state of absorbed attention is desirable and beneficial for the skilled athlete and performer (Quarrick, 1989), it can be hazardous for those who monitor systems such as aircraft" (Pope and Bogart, 1992, p. 450).

Attention management training has been proposed as a countermeasure to the occurrence of such hazardous awareness states. The management of attention is the problem that Davenport and Beck tackle in their 2001 book, *The Attention Economy*. They state: "There is only so much attention to go around, and it can only be increased marginally by somehow exercising the brain or by adding new sentient beings to the planet" (Davenport and Beck, 2001, p. 10). They further observe: "Video games, for example, are clearly proficient at getting and keeping the attention of our children's generation. [...] Important messages will have to be embedded in some sort of live-action game" (Davenport and Beck, 2001, p. 76). These authors cite another NASA Langley Research Center invention as the basis for attention measurement: "... since attention is a cerebral phenomenon ... the best way to monitor it is directly through capturing and analyzing brain waves. Thus the ultimate in attention-monitoring technology is an approach developed by the National Aeronautics and Space Administration (NASA) and licensed to a company called Capita Research Group. The technology uses conventional electroencephalograms (EEGs) and the NASA technology to analyze the size, shape, and speed of electrical activity in the cognitive sections of the brain. The brain activity, measured through a special headset, is used to construct an *engagement index*—in the words of the company, 'a measure of attention, interest and involvement recorded from the test subjects'" (Davenport and Beck, 2001, p. 51). This same EEG-based engagement index does the modulating in the ADD application of NASA's brainwave modulated video games, embedding "brain exercise" in an entertaining medium.

Both inattention and stress overload play a substantial role in impairing pilot performance and producing flight hazards. Biofeedback training can foreseeably help reduce the occurrence of these "hazardous state of awareness" by teaching pilots to maintain the necessary physiological conditions for good cognitive and psychomotor performance under the circumstances which are most likely to produce inattention or dysfunctional stress.

Instrument Functionality Feedback (IFF) Training is a new concept for training pilots in maintaining the physiological equilibrium suited for optimal cognitive and motor performance under emergency events in an airplane cockpit (Palsson and Pope, 1999). It is a novel training concept for reducing pilot error during demanding or unexpected events in the cockpit by teaching pilots self-regulation of excessive autonomic nervous system (ANS) reactivity during simulated flight tasks. The training method (a) adapts biofeedback methodology to train physiological balance during simulated operation of an airplane, and (b) uses graded impairment of control over the flight task to encourage the pilot to gain mastery over his/her autonomic functions. In Instrument Functionality Feedback Training, pilots are trained to minimize their autonomic deviation from baseline values while operating a flight simulation. This is done by making their skin conductance and hand temperature deviations from baseline impair the functionality of the aircraft controls. Trainees also receive auditory and visual cues about their autonomic deviation, and are instructed to keep these within pre-set limits to retain full control of the aircraft.

This training method teaches video game players to incorporate autonomic or brainwave physiological self-regulation into video game playing without the need for conscious attention to such regulation. The method works through a two-step mechanism of instrumental learning and classic conditioning. Through the player's effort and inherent motivation to master the game task, and through repeated associations in accordance with established psychological learning principles, the healthy changes will generalize to other life situations.

"... creative personalities ... seem to be capable of switching to a more relaxed mode which investigators have described in terms of 'effortless experiencing,' 'divergent thinking,' 'remote associations,' and the utilization of primitive levels of thought (Barron and Harrington, 1981). This was demonstrated in one study which found that creative and noncreative subjects have different EEG patterns when working on tasks that require innovative solutions (Martindale, 1975). The noncreative subjects apparently attacked the tasks intellectually, with intense and discriminating mental activity; and their EEG records showed high cortical arousal and focused attention. The creative subjects, on the other hand, approached the tasks in a more leisurely fashion. Their EEG records were indicative of low cortical arousal and diffuse attention; they contained a significant amount of alpha rhythm, which reflects relaxed and nonpurposeful thinking. In other words, while the noncreative subjects worked at the tasks, the creative ones toyed with them" (Quarrick, 1989, p. 165). Might modulated video games that require the production of these brainwave patterns foster creativity?

Recent studies that won the first prize in the Golf Magazine 2001 "Science in Golf " competition have identified the brain activity patterns and stress responses associated with effective golfing. "'The EEG data tells us that it's not the level of anxiety that determines performance, but how the brain processes the increase in activity,' says Dr. Crews. 'Our chokers had the left side of their brain doing most of the work when the pressure increased. The successful golfers had comparable increases in brain activity, but that activity was spread evenly throughout both sides of the brain.' In other words, get the more creative right side of the brain involved if you want to produce in the clutch" (Crews, 2001, p. 95). Sports tasks, such as putting, archery, sharp shooting, basketball foul shooting, tennis serving, and darts require regulation of physiological state in conjunction with a skill base at a critical moment of execution for success. Research by Crews and Landers (Crews, 1993) showed that when golfers, for example, produce an optimal physiological alpha state before the discrete event of putting, there was less error. Would the

psychophysiological skills practiced in a modulated golf or sharpshooting video game, requiring that the player produce these optimal brainwave patterns and control anxiety responses, transfer to the golf course or firing range?

Poole (2000) and Herz (1997) claim that video games are rewiring our minds (Poole, 2000, p. 231). If that is the case, biofeedback-modulated video games enable us to have some say in just what rewiring takes place. Entertaining games that incorporate biofeedback in the background may offer a palatable and effective way to systematically guide the cerebral rewiring occurring during prolonged video game playing towards fostering creativity, concentration skills, precision motor skills, and other valuable abilities.

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