

Neurofeedback: Is there a potential for use in education?

Abstract

There is evidence that athletes, musicians, dancers and those suffering with behavioural problems like attention deficit disorder amongst others are benefiting from neurofeedback. Neurofeedback is the presentation in real time of information about the state of the brain received via electrodes placed on the scalp. Such systems allow the wearer to practice generating the state of mind most beneficial to their sport, art or desired behaviour. Although there are issues about the reliability, the need for personalisation and time required to be beneficial this technology is becoming more widespread. In this article we look at some of this research and existing systems, their uses, some of the concerns, and the potential this has for education.

Keywords

Neurofeedback, education, ADHD, sports, performance

1 Introduction

In order to consider the potential of neurofeedback in education we need to understand what it is (and is not), what already exists and the type of feedback that can be offered, and the limitations of such systems.

1.1 So what is neurofeedback?

Neurofeedback is a type of biofeedback. Biofeedback is simply measuring a quantifiable bodily function, for example, blood pressure, heart rate, skin temperature, sweat gland activity, muscle tension etc and conveying this information back in real-time. This information could be visual, audio, haptic (touch) or a combination of these, and focus on specific regions or types of brain activity.

Such systems can be used as a variation of "operant conditioning", ie rewarding desirable behaviour and discouraging undesirable behaviour. The idea is that through seeing such representations the person will be able to practice changing this function, first viewing the feedback and then without such representations, and finally being able to summon up such states without the system.

As the name suggests neurofeedback displays the brain state of the person. This usually involves monitoring the person's brainwaves. Brainwaves are the results of neurons firing at different intensities and rates in different areas of the brain. The pattern of firing, intensity, and location relate to the kind of activity being performed. Brainwaves are described by their: i) amplitude, the index of strength or intensity shown by height and ii) the cycles per second measured in Hertz (Hz).

Four of the common brainwaves are beta, alpha, theta and delta. When you are deeply engaged in an activity the amplitude of the majority of your brainwaves is small, yet they occur rapidly, 12-30Hz per second. These are beta waves. As you become more relaxed the amplitude increases but the amount decreases – these are alpha waves. As you drift off to sleep the dominant amplitude increases again and the rate drops to 4-8Hz, these are delta waves. And when finally you fall asleep the amplitude of the majority of waves is higher still, but the rate reduces to 0-4Hz (see **Error! Reference source not found.**).

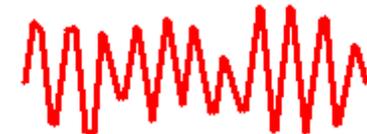
Name	Amplitude (Hz)	Example of trace	Activity
Beta	12-30		Awake and processing information
Alpha	8-12		Awake, relaxed, and stress free
Theta	4-8		Early sleep stages and drowsiness
Delta	0-4		Deep sleep

Table 1: Common brainwave descriptions

Brainwaves are monitored by non-invasive electrodes attached directly to the scalp or through a cap with the electrodes attached. The recording mechanism is electroencephalography (EEG), and neurofeedback is sometimes referred to as EEG biofeedback. As stated the positions of the electrodes are important, as different areas of the brain are associated with different functions. For example, if elite archers are trained to increase alpha waves in the left temporal area (the front left part of the brain) their accuracy improves; a similar increase on the right side reduces performance¹.

It should be noted that electrodes on the scalp can be used to monitor things other than brainwaves. They can be used to detect Slow Cortical Potentials (SCP) - very gradual changes in neurons that last from a fraction of a second to several seconds. Amongst other things these are associated with conditions like epilepsy or attention disorders; research is being done to train sufferers to make the SCP negative, thus stopping neurons firing and bringing on fits or inattentive sessions.

Such scanning may have no training intent at all. Electrodes can be used to measure neural markers, or distinct electrical signals emitted by the brain (Event-Related brain Potentials – ERPs). One such marker can be found in newborn infants and is an effective method of predicting which children will be poor readers or dyslexic at 8 year olds. Another ERP has been identified which may take a similar role but this time provide an early indicator of children who will struggle while performing mathematical tasks².

Research is also being used to detect other traits. In 1983 Martindale and colleagues³ hypothesised and found that highly-creative people exhibited greater right-hemisphere than left-hemisphere EEG activity during creative performance which was not found in less-creative people. And EEG can be used to identify what types of brainwaves are associated with working memory (theta) and higher hertz levels of alpha waves with memory retrieval⁴.

¹ See Landers DM, Han M, Salazar W, Petruzzello SJ, Kubitz KA, & Gannon TL (1994). "Effect of learning on electroencephalographic and electrocardiographic patterns in novice archers." *International Journal of Sports Psychology*, Volume 22, pp56-71.

² Friedrich, M. (2008). State-of-Science Review: SR-D14, Early Neural Markers of Language, http://www.foresight.gov.uk/Mental%20Capital/SR-D14_MCW.pdf

³ Martindale, C, Hines D, Mitchell L & Covello E (1983) "EEG alpha asymmetry and creativity". *Personality and Individual Differences*, Volume 5, Issue 1, pp77-86.

⁴ Vernon DJ. (2005). "Can Neurofeedback Training Enhance Performance? An Evaluation of the Evidence with Implications for Future Research." *Applied Psychophysiology and Biofeedback* Volume 30, Issue 4, pp347-364

Finally it should be noted the field of brain computer interaction (BCI) shares some aspects with neurofeedback but they are **not** the same. BCI's goal is enable systems to recognise the user's request, rather than assist the person to amend their brain patterns - although the two may overlap as to achieve the action the person may have to train themselves to generate those patterns. Unlike neurofeedback BCI may be invasive, ie require implants in order to control the external computer, however this is not always the case. For example there is evidence that electrodes can detect choices, for example Dr Mick Grierson at Goldsmiths, University of London, had devised a system whereby the wearer of the electrodes can select a note he wishes to be played. This works as when the wearer sees his desired note on screen it unconsciously triggers a change in brain activity which is detected by the system which goes on to play the note. In trials there was a 75% success rate⁵. This idea that decisions can be recognised is also being investigated by commercial and research institutes.

Emotiv⁶, for example, are in the process of developing a system initially for games that recognises what object a player wants to move and enables that to be moved on screen, moreover they claim it will recognise non-conscious emotions, such as stress, happiness, sadness, frustration and use these to change the game play. Thus a player who is struggling with a task may be offered help after a certain time, if they are excited game play may speed up, or an avatar may respond angrily if the player is angry. The idea is to make the game more engaging.

Emotiv are also looking at having thoughts directly control external devices, hopefully allowing people with disabilities to communicate and perform tasks, including driving a car. Although as yet systems do not exist as complex as those in the 1982 film Firefox in which the fighters weapons systems were thought activated, although there are systems that can monitor brain state and prompt a pilot to eject if levels of attention drop.

Research activities include a workshop on BCI for HCI and Games which looked at these issues at the Computer Human Interaction (CHI) 2008 conference. Also in 2008 a four year research project was started looking at BCI for people with disabilities, but the lessons learnt about designing interfaces – especially for entertainment – are generally applicable (<http://www.tobi-project.org/welcome-tobi>).

1.2 Existing neurofeedback systems

All neurofeedback systems involve electrodes being attached to the scalp. However, there are variations on volume and location of electrodes required and the format of the feedback itself. A simple system may require the person being monitored to relax, thus generating more alpha waves, and if they succeed a bar representing the amplitude of one brainwave may increase, and another one decrease – or the graphics could be more calming, so if they maintain alpha as the dominant brainwave they may make an onscreen flower blossom. If successful the person may hear a tone as well as see it represented visually and possibly score a point.

In this section five commercial systems that demonstrate the variation in feedback forms that are available are described. Medical and research systems often have more electrodes with greater emphasis on their location although the feedback tends to be restricted to more simplistic visual and audio representations⁷.

⁵ <http://www.gold.ac.uk/news/archive/june2008/title,2575,en.php>

⁶⁶ www.emotiv.com

⁷ For example see the work of Steul and his colleagues where the representations are of a smiley face and positive if the brainwave is changed successfully, Strehl U, Leins U, Goth G, Klinger C, Hinterberger T, & Birbaumer N. (2006). "Self-regulation of slow cortical potentials: A new treatment for children with attention-deficit/hyperactivity disorder." *Pediatrics* Volume 118, Issue 5, pp1530–40.

The system developed by Alpha-Active Ltd⁸ displays brainwaves purely visually, as shown in Figure 1. It is designed for use by sportsmen and women and unlike the other systems described is to be used in conjunction with a coach or therapist. Thus it is not true neurofeedback in that the information is mediated. In this setup the athletes practice normally although they have the electrodes attached to the scalp enabling the coach to view their brainwaves in real time. Through this observation they can relate performance to brain state and coach more effectively at the time or by playing back to the athlete afterwards and discussing what happened.

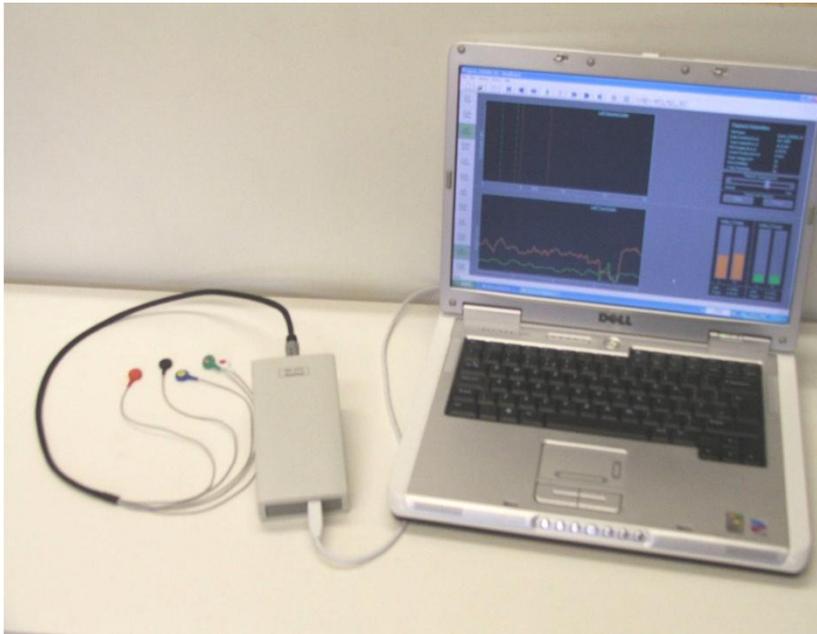


Figure 1: Alpha Active system

A commercial system, Mind Media NeXus-10⁹, also displays the brainwaves but in a more game-like setting. Unlike the Alpha Active system, the player receives the feedback directly onscreen and during the game is required to practice changing brain states. In this game, the player races the caterpillars by increasing or decreasing brainwaves as required.

⁸ See www.alpha-active.com

⁹ <http://www.mindmedia.nl/english/aboutneurofeedback.php>



Figure 2: Screenshot from the MindMedia neurofeedback game for children

Another popular system is the Mindball® Game¹⁰. This displays the alpha waves, as shown on the screen behind the players in Figure 3 but feedback is also given through the movement of the ball between the two players, each wearing electrodes and trying to “score” by being more relaxed than their opponent and thus moving the ball towards them.



Figure 3: Children playing the Mindball® Game

¹⁰ http://www.mindball.se/egg_biofeedback.html

Other systems may have no graphical feedback at all. Although not directly a training system MindFlex¹¹ by Mattel – which is being marketed as a game, gives feedback on the number of theta waves being generated. These waves cause a fan to turn, raising a ball in the air, which must then be navigated through a user constructed course that is rotated past the ball.



Figure 4: Mattel's MindFlex system

The final example in this section is the commercial product PlayAttention. This system is based on work done for NASA's Langley Research Centre. Researchers were developing an adaptive simulator system in their flight deck research. The idea was that by monitoring the pilots' brainwaves they could determine the optimum level of automation to keep the pilots engaged. They expanded this idea into a training system, so that the pilots' brainwaves controlled the level of automation, the more engaged they were the higher the level of automation. In PlayAttention the feedback is not explicit, the user plays a computer game and their brainwave feedback is in the form of the ease of control the person has via the joystick¹².

1.3 Limitations of such systems

Both academics and commercial researchers are faced with limitations to the use of neurofeedback. The most obvious is the difficulty in monitoring the brainwaves. Unlike being in hospital where there is less choice people may not want to have too many electrodes placed on the scalp, especially if this involves gel to improve the connection.

Secondly movement of the head or changing facial expression can interfere with detection - the system is equally likely to track blinks as it is brainwaves. And each individual can have slight variations in brainwaves related to states. Thus algorithms have to be designed that are accurate no matter who is using it, where they are using it, and what other activities they are doing in parallel. Research to compensate for movement, such as in sports or games, is currently under development. For example, Alpha-Active have a patented algorithm to improve stability in neurofeedback while a

¹¹ As described in:

<http://www.telegraph.co.uk/scienceandtechnology/technology/technologynews/4126913/Mind-game-where-players-use-brainwaves-to-float-ball-through-hoops-unveiled.html>

¹² This is mentioned by NASA (http://www.sti.nasa.gov/tto/spinoff2003/hm_2.html) or for a more detailed description see Palsson, O. S. and A. T. Pope (2002). "Morphing Beyond Recognition: The Future of Biofeedback Technologies." *Biofeedback*, Volume 30 Issue 1, pp 14-19.

person is moving¹³. However there is still more research to be done in investigating hardware and the underlying algorithms within neurofeedback systems.

To further complicate feedback the optimal brainwaves need not be identical between people performing the same task. This might be to do with the state of the brain, a footballer who has done a lot of headers for example, might display a different state to another footballer without that experience even though they are doing the same task well¹⁴. Thus training to increase alpha waves in the same area of both players would be ineffective.

Finally, for training systems there needs to be an accurate knowledge of where the brainwaves need to be dominant. It is possible that neurofeedback training can be detrimental, that is, you can make the athlete worse. As stated by repetition it is hypothesised the subject will learn to generate the desired brain activity in specific locations at will. In 1991 a study was conducted by Landers and his colleagues where archers were trained to shift the level of cortical activity towards more negativity in the left or right temporal regions. Those trained to the left improved accuracy, while those now using the right were worse. This indicates – though does not confirm - neurofeedback training has an impact¹.

2 Neurofeedback uses

Originally neurofeedback was investigated by the medical profession who had access to accurate EEG systems. They focused on brain irregularities, most commonly epilepsy and attention and behaviour disorders. However, there has also been work with those suffering anxiety or depression, headaches, alcoholism and sleep disorders. As previously stated, the research has not been solely around the brainwaves. Research for conditions like epilepsy, migraines or ADHD participants often involves showing patients their SCP activity and encouraged to learn how to increase the SCP to dampen neuron firing to reduce the firings that cause the problem.

In this section we will focus on neurofeedback systems that have a direct if not formal educational aspect: sports, to improve artistic performance, and as a treatment for ADHD. This is in order to support the next section considering the potential of neurofeedback for education.

2.1 Neurofeedback systems in sports

The use of neuroscience in sport is a multi-million dollar business, for example, Lewis Hamilton has a neuroscientist on his team which helped him become European karting champion in 2000 with the maximum points achievable and still works with him¹⁵. With respect to neurofeedback in sports there appears to be three purposes.

The first is to encourage the athlete to enhance brain waves in the appropriate area. For example the work by Lander and his colleagues who have looked at marksmanship and where the player needs to practice generating alpha waves. In other sports it may be that beta needs to be dominant in certain areas. Improved balance, necessary for example in gymnastics, skiing, and tennis, has been shown if the athlete is encouraged

¹³ Details can be found in Griffiths MJ, Grainger P, Cox MV & Preece AW (2005). "Recent Advances in EEG Monitoring for General Anaesthesia, Altered States of Consciousness and Sports Performance Science" *3rd IEE International Seminar on Medical Applications of Signal Processing*.
http://www.staplethorne.co.uk/Alpha_Active_IEE_2005.pdf

¹⁴ See Hammond DC. (2007). "Neurofeedback for the Enhancement of Athletic Performance and Physical Balance." *The Journal of the American Board of Sport Psychology*
(<http://www.americanboardofsportpsychology.org/Portals/24/ABSP-JournalHammond1.pdf>) Volume 1.

¹⁵ <http://www.lewis-hamilton.org.uk/about>

to decrease theta and reinforce beta brainwaves through sensors placed at the back of the head¹¹.

The second area is to assist entering "the zone". This is the calm state whereby they are performing at the peak of their abilities but with what seems little conscious effort. What the zone is depends on the sport. For marksmen (shooting, archery, and golf) this can be seen as having alpha waves dominant – so expert sportsmen generate more alpha waves and fewer beta whilst in action compared to novices¹⁶. Systems like that developed by Alpha-Active allow an athlete to monitor brainwaves while practicing and after the sessions relate the brainwaves generated during their training to their performance. By relating state to performance they should find entering the zone easier.

The third use is related to the second and is not strictly speaking neurofeedback. Such systems can be used as a diagnostic tool: it can distinguish players with the potential to become focused by observing how easily they can make a certain brainwave dominant¹⁷. People who can do this should be able to carry over this ability to the court or pitch.

Research shows that there is one correct neurofeedback training programme per sport, or even per position in the team. Beneficial neurofeedback training programmes need to be varied according to whether the player has suffered head injuries, whether they suffer from ADHD or epilepsy, and their preferred playing style (footballers who repeatedly head the ball for example may experience changes in EEG¹⁸).

As an aside computer gamers can be compared to athletes. In both it is possible to reach the zone and back in 2002 it was suggested athletes become absorbed in such games in order to feel the meditative concentration – the dominance of alpha waves - and hopefully recognise and transfer this mental state to when they were participating in their usual sports¹⁹.

2.2 Neurofeedback to improve artistic performance

Work with musicians and dancers has shown similar results to that of sportsmen. For example, there is the possibility of recognition. Trained musicians have a higher level of alpha waves when passively listening to music than non-musicians, although they generate more beta brainwaves in the processing of music²⁰.

And like athletes musicians and performers can enter the zone. So not only can neurofeedback be used to recognise the potential for musicianship neurofeedback training has been shown to improve performance – including interpretative imagination and musical understanding, and reduce stress levels. An example of this research is that done by Gruzelier and his colleagues at The Royal College of Music (RCM) in London²¹. In some of the earliest studies students were trained to generate frequencies of 12-15Hz, then 15-18Hz and then producing a high theta over alpha ratio in ten 45 minute sessions

¹⁶ For an example see the research on marksmen by Haufler, A. J., Spalding, T. W., Santa Maria, D. L., & Hatfield, B. D. (2000). Neurocognitive activity during a self-paced visuospatial task: Comparative EEG profiles in marksmen and novice shooters. *Biological Psychology*, 53, 131-160.

¹⁷ DT Max describes coaches using neurofeedback to confirm that the young tennis player is adept at entering the "zone" compared to her opponent. <http://wired4peakperformance.com/articles-resources/wired-for-victory.php>

¹⁸ Tysvaer AT, Stroll OV, & Bachen I. (1989). "Soccer injuries to the brain: A neurologic and electroencephalographic study of former players". *Acta Neurologica Scandinavica*, Volume 80, pp151-156. Cited in <http://www.americanboardofsportpsychology.org/Portals/24/ABSP-JournalHammond1.pdf>

¹⁹ The BBC reported such research back in 2002 <http://news.bbc.co.uk/1/hi/technology/2154092.stm>

²⁰ Petsche H, Lindner K, Rappelsberger P, & Gruber G. (1988). "The EEG: An adequate method to concretize brain processes elicited by music". *Music Perception*, Volume 6, pp133-159.

Petsche, H., Richter, P., von Stein, A., Etlinger, S. C., & Filz, O. (1993). EEG coherence and musical thinking. *Music Perception*, 11(1), 117-151.cited by Vernon

²¹ Egner T & Gruzelier J. (2003). "Ecological validity of neurofeedback: Modulation of slow wave EEG enhances musical performance". *NeuroReport*, Volume 14, Issue 9, pp1221-1224.

divided into these three tasks. All students improved in performance, with a correlation between improving performance and success in the alpha-theta protocol. In the second study students just did ten 15 minute sessions on the high theta to alpha ratio and there were significant improvements in overall quality, musical understanding, stylistic accuracy and interpretive imagination. It should be noted that this is not evidence of improved actual learning.

Other researchers have been investigating impact of training in the alpha-theta protocol in the areas of ballet, ballroom dancing, folk singing and novice singers, all with similar results to that at the RCM. As recently as 2008 it was shown to improve the performance of singers at Stuttgart Opera²².

It should be noted that such studies are not conclusive, as there is no control for the order of treatments and there may be confounding factors such as expectation.

2.3 Neurofeedback to assist students with ADHD

ADHD is a neurological disorder characterised by persistent inattention sometimes coupled with hyperactivity and impulsiveness. Despite the name it is not actually a lack of attention per se, rather sufferers have fleeting attention. Around 3-6% of 5-12 year olds in the UK are diagnosed with ADHD²³. Studies have shown that students with ADHD often had lower average marks, more expulsions, and leave education earlier²⁴. Given this, and later problems - the greater tendency of those with ADHD to have criminal records, an employment history with more jobs and substance abuse compared to those of similar intelligence without ADHD²⁵, scientists have been trying to treat ADHD.

In addition to chemical approaches to treatment, such as Ritalin, scientists have used positron emission tomography (PET) and functional Magnetic Resonance Imaging (fMRI) scans to clarify the relationship between surface EEG frequency rhythms and the underlying mechanisms responsible for variations in alertness and behavioural control. In the diagnosis phase those with ADHD are often shown to have underactivity in frontal, central and midline cortical regions (the grey matter in the brain) and elevated theta power and reduced alpha and beta powers in this area (varying between different sufferers). However, there is an absence of consistency in this diagnosis. It should also be noted that neuroscience suggested that improving working memory in people with ADHD may be beneficial, and it is²⁶.

In 2005 a meta-analysis of studies was conducted by Monastra and his colleagues. They were investigating the hypothesis that training could normalise these rhythms with clinical benefits. The majority of studies focused on increasing beta brainwaves (usually those within 12-15Hz) and suppressing theta brainwaves; the research variations are where the electrodes are placed on the scalp. They concluded that training was not detrimental – in most cases the outcome – even long term – was positive, but that there

²² Gruzelier J (2008) A theory of alpha/theta neurofeedback, creative performance enhancement, long distance functional connectivity and psychological integration. *Cognitive Processing*, <http://www.springerlink.com/content/r7mm585811835t24/>

²³ Goswami U. (2008). Learning difficulties: Future challenges. *Mental capital and wellbeing project*, http://www.foresight.gov.uk/Mental%20Capital/Learning_difficulties.pdf

²⁴ Mannuzza S, Klein RG, Bessler A, Malloy P, & LaPadula M. (1998). "Adult psychiatric status of hyperactive boys grown up". *American Journal of Psychiatry*, Volume 155, pp493–498, cited in Monastra VJ, Lynn S, Linden M, Lubar JF, Gruzelier J, LaVaque TJ (2005) Electroencephalographic biofeedback in the treatment of attention-deficit/hyperactivity disorder. *Applied Psychophysiology and Biofeedback*. Volume 30 Issue 2, pp95-114

²⁵ Claude & Firestone, 1995, Weiss & Hechtman, 1993 and Murphy & Barkley, 1996 cited in Monastra et al (1995)

²⁶ See p14 of Howard-Jones P. (2007). Neuroscience and Education: Issues and Opportunities, Teaching and Learning Research Programme, Economic and Social Research Council, <http://www.tlrp.org/pub/documents/Neuroscience%20Commentary%20FINAL.pdf>

was insufficient controlled evidence to categorically say it was beneficial. It should be noted that training those with ADHD to improve attention without using neurofeedback is equally effective.

Despite the absence of conclusive scientific proof regarding EEG feedback there is substantial anecdotal evidence to support neurofeedback's use in commercial systems to improve attention for ADHD sufferers. For example, the work by the NASA research team mentioned previously has been extended; instead of a flight simulator the researchers replaced it with a commercial modified videogame. If a player produces more beta brainwaves the game controller or joystick is more responsive; if theta brainwaves are dominant it becomes more sluggish. The results were similar to studies where more traditional tasks were given, increasing the size of a bar representing a frequency for example. However, the task itself was more motivating²⁷. This research led to the Play Attention system. In which the wearer of a sensor lined helmet plays modified commercial games which do not require hand-eye co-ordination, instead the level of focus impacts the ease of the joystick control, more focus and the game is easier to manipulate. The idea is that the game is motivating enough so that wearer learns to ignore distractions, develop memory skills, finish tasks, and become organized. Through repetition the wearer can transfer these skills to life outside the game – unlike clinical systems it is **not** meant to directly teach the wearer how to change their brainwaves, as they state, changing brainwaves does not make one more organised, focused, and have a better short term memory.

3 The educational potential of neurofeedback systems

In the previous section we looked at neurofeedback in sports, performing arts and ADHD. From this it seems that the important things about such systems are:

- They are used over extended periods of time;
- They are used in conjunction with other training techniques;
- And there needs to be an understanding of what brainwaves the individual needs to generate.

This work also shows such feedback can be beneficial, and at the very least is not detrimental (unless deliberately set out to be so). Yet so far there is little direct evidence that neurofeedback can improve formal learning – although there is evidence that it can improve the ability to be focused or relaxed. This in turn may enhance the learners ability to focus and hence what is learnt. However, what is clear is that there are areas of concern around the potential of neurofeedback in education which are discussed next.

3.1 Issues

Although not an exhaustive list the following suggests issues that need to be considered during the development and implementation of educational neurofeedback systems.

Intrusion

As stated EEG is not invasive, therefore it cannot be used to suggest ideas to the wearer. But what if in the longer term we were able to recognise what each neural signal denotes rather than generic pictures of our mood or deductions from brainwaves? Thus what if we could tell whether or not an idea has been grasped? What would this mean for teachers if they could see who has understood an explanation without having to wait for an exercise showing whether or not the concept has been mastered? It may be a useful tool for indicating whether teaching methods need to be altered, or it may be an assessment tool technique, monitoring how long people are interested or focused as well

²⁷ Palsson OS & Pope AT (2002). "Morphing Beyond Recognition: The Future of Biofeedback Technologies." *Biofeedback* Volume 30 Issue 1, pp14-19



as their actual performance. Guidelines for usage therefore need to be considered in advance.

These systems may also show the teacher which learner has an aptitude for a subject by the volume of brainwaves generated in certain areas and therefore be used to assign students to subjects regardless of their preference. And because it is non-verbal the age of the student is irrelevant – although the brainwaves of young children differ from adults so recognition may be problematic. Are there moral issues about such “sorting” of students

by their ability?

A further concern about the intrusiveness of such monitoring is the possibility that headsets that stimulated a state rather than monitored it could be built. For example, would ensuring all golfers had the optimum level of alpha waves in the correct region improve that game?

Reliability

As mentioned the system needs to take account of the wearers movement and that the electrodes are on the appropriate place, which may vary slightly from person to person. To make a meaningful educational system the system itself must be more reliable, but to be useful it may need to be personalised to an extraordinary extent.

Expense

Following on from reliability and the need for personalisation there is the cost of accurate EEG equipment, the necessary training to calibrate the system for the individual and to ensure that the training is in the relevant area for the individual. This may lead to a two tiered system; with the more affluent having better and more stylish systems. Although it may seem trivial students may not want to wear baseball caps, or adapted bicycle helmets in classes so the issue of aesthetics will need to be investigated.

Figure 5: Emotiv helmet (see www.emotiv.com)

Note that such accuracy for some purposes, such as ADHD, systems is less important as they incorporate other learning techniques may reduce this impact.

Neuroscience considerations

It should also be noticed that neurofeedback is not the only area of neuroscience that could benefit education. ERPs could be measured as a matter of course, and if the markers are detected for reading problems, dyslexia and mathematical difficulties suitable teaching methods could be employed before the problems take hold. And it may be possible to confirm ADHD by examining scans showing the volume of beta and theta brainwaves generated in certain parts of the brain. In addition to the diagnostic potential of neuroscience a better understanding of the brain may lead us to be able to model the learning process more accurately, and hence adapt the teaching.

3.2 What should be considered for educational systems?

So what is the potential of neurofeedback in general education? Research into games is already enabling onscreen activities to respond to the ‘affective state’ of the user, for example, being bored, angry, excited, confused. This could be directly transferred into education environments that can present information and exercises at an appropriate level and in an appealing way. Or the feedback the system uses about the persons state could be used as neurofeedback itself; so they practice focus.

From existing research it seems the most likely use of neurofeedback in education is to be one of many tools that support a learner, following the model of systems like PlayAttention which uses multiple techniques over time for changing behaviour. These systems could be similar to those used to enter the zone or improve artistic performance by practicing to generate relevant brainwaves, or indirectly through the development of a learning environment in which desired traits are encouraged. Initially it seems that generic states will be the area of focus as personalisation will require monitoring to identify the state then training to replicate rather than just the latter.

Also work will need to be done on the type of interface for education. Should it relate directly to a subject or can it be more abstract and entering the state be sufficient? Can shared environments be created to be more engaging or like Mindball encourage competition to achieve the desired state? Also the appearance of the interface and electrodes will be important, academic research has not yet focused on aesthetics.

Finally, neurofeedback seems an unsuitable method of communicating information, though as stated it can be an appropriate medium for ensuring that information is presented meaningfully. Therefore it would seem sensible to use such systems to engage and monitor rather than teach per se.

3.3 A few final thoughts

Methods of detecting brainwaves and other brain states will become more reliable and the systems will become cheaper. Moreover, we will have a better understanding of where and what type of brainwaves correspond to specific activities and high performance. Although such knowledge and systems do not exist at the moment thinking about their potential and how we would use them **if** they existed is important in order that effective education tools can be created rather than banning such technology from the classroom. All those involved in formal learning, teachers, students, academics, and parents, will need to be involved to create systems that are useful and usable.

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