Abstract

The *Bio-Optic Surveillance System* is a device monitoring and suppressing Attention Deficit Hyperactive Disorder (ADHD) symptoms in real time so that patents with ADHD can focus on important tasks such as studying and working. It utilizes optogenetics technology to control dopamine releases in the brain to revert or prevent ADHD symptoms. Light-sensitive proteins, called opsins, are injected and bound to neurons in prefrontal cortex and striatum area of a patient's brain. The now light-sensitive neurons can then be activated by the device to release dopamine, which supresses ADHD behaviors. The patient's brain wave is monitored by an electroencephalography scanner (EEG) in real time. When ADHD symptoms are detected, the device automatically turns on micro LEDs that shine specific spectrum of light on the light sensitive opsins implanted, which in turn simulate human nerve cell signals to stimulate release of dopamine. This process reverts ADHD symptoms.

The Bio-Optic Surveillance System

Problem overview

ADHD stands for the Attention Deficit Hyperactive Disorder. It is a common psychiatric disorder of neurological development due to genetic or biological factors that affects both children and adults. A person with this disorder will experience problems with attention, hyperactivity and/or acting impulsively which means to act on instinct or without thinking. Some symptoms of this disorder include being easily distracted, missing details, becoming bored easily, fidgeting, being impatient and interrupting conversations. Despite being the most studied and diagnosed psychiatric disorder, there is still no cure for the disorder but there can be treatments and medications to treat and reduce the effects of the syndromes.

Present Technology[1]

Cause of ADHD

The prefrontal cortex and striatum in the human brain are responsible for regulating actions, planning, focusing, performing executive functions, and so on. A type of nerve cells called neurons [2], are responsible for relaying information throughout the neural network. Neurons transmit information by releasing chemicals called neurotransmitters, which are responsible for communication between neurons. The current hypothesis supposes that ADHD is at least in part caused by an insufficient quantity of dopamine[3], a type of neurotransmitter, in the prefrontal cortex and striatum. Insufficient dopamine results in “satisfaction” signals not being transmitted properly[4], thus causing a feeling of "lack of satisfaction". In essence, for ADHD patients’ brains are not able to know when

tasks as worthwhile, making it difficult to concentrate; the brain is too busy trying to find something else that is worthwhile.

Medication

There are many medications available today to alleviate ADHD symptoms, but not to cure it. There are three kinds of medication types available today: stimulant drugs, non-stimulant drugs, and tricyclic antidepressants. However, these drugs are not always effective.

The first class of drugs is called stimulant drugs. It works by increasing the release of dopamine and slowing the process of reabsorption at the same time. This type of drug is well tested, since they have been used to treat symptoms of ADHD for decades. Unfortunately, they are only effective on 70% to 80% of patients with ADHD.

Another type of drugs is called non-stimulant drugs. It works similar to stimulants, but affecting a different chemical called norepinephrine. Compared to stimulant drugs, non-stimulant drugs do not cause sleeplessness, and a longer lasting and smoother effect than most stimulants. However, they do have some greater disadvantages comparative to stimulant drugs, such as an upset stomach, decreased appetite, fatigue, dizziness, and so on.

Aside from stimulant and non-stimulant drugs, tricyclic antidepressants can also be used in treating ADHD. Although this type of drug is mainly used on patients with depression, they also work by increasing the amount of norepinephrine.

Drawbacks of Present Technology

As mentioned earlier, many drugs increase the concentration of dopamine or norepinephrine in the brain. Appropriate stimulation, caused by dopamine and norepinephrine, of the brain and central nervous system increases "satisfaction" allows

them to focus more effectively. While there are drugs currently available to increase dopamine releases, they have a few drawbacks:

First of all, the dosage is hard to measure. Different ADHD patients react differently to dopamine, and even for the same person, the brain activity is different at different times. So the dosage is a trial and error process to figure out the best dosage, and even if the average dosage required is figured out, it is not possible to tune the dosage in real time according to the patient's current brain activities.

Second, those drugs bring a risk of drug abuse, including stimulants abuse and addiction to stimulants[5]. There have been reports of people using ADHD stimulants that were not prescribed for them. People have crushed and snorted Ritalin tablets, or dissolved the drug in water and taken it intravenously. Studies show that abusing Ritalin can lead to dependence on the drug[6].

Third, the drugs can not accurately target a specific area of the brain. Instead, they have an effect of the entire brain. This causes unrelated circuitry in the brain to be affected, causing undesirable effects such as loss of appetite, sleep problems, and mood swings.

Finally, the effect of the drugs cannot be monitored and controlled in real time. Patients get feedback only when revisiting their psychologists, but even so, there is no objective recording system other than verbally described feelings to be judged by the psychologist.

History [7]

ADHD was first recorded in the 18th century as a "mental disorder" and development has gone from there. It was later called "a morbid defect in moral control" by Sir George Frederick Still. In older times, people with ADHD would have been preferred by natural

selection, because they would have quicker responses and superior hunting skills. Their skills would benefit society (they might find new food sources and so on.) even if it was harmful to individual.

In 1775, German physician and author Melchior Adam described the symptoms of ADHD in his book *Der Philosophisce Arzt*. He may possibly be the first one to recognize “ADHD”. In 1902, ADHD was recognized as a disorder. There were recorded cases of impulsive behaviour by Dr. Still. He named it “Defect of Moral Control”, and believed it to be a medical problem. In 1922, ADHD was diagnosed as “Post-Encephalitic Behaviour Disorder”. In 1937, stimulants were used to treat children with ADHD. Dr. Charles Bradley introduced Synaptol. In 1956, Ritalin (another stimulant) became available to treat children who were considered hyperactive. In the 1960s, more stimulants were used to treat hyperactive children. It was called "Minimal Brain Dysfunction" at the start of the decade, but was later changed to “Hyperkinetic Disorder of Childhood”. In the 1970s, more symptoms were recognized, such as impulsiveness, lack of focus, and daydreaming. Impulsiveness was divided into the verbal, cognitive, and motor subtypes. In 1980, “Hyperkinetic Disorder of Childhood” was re-named “Attention Deficit Disorder” by the American Psychiatric Association. In 1987, the name was revised to “Attention-Deficit Hyperactivity Disorder” (ADHD), commonly used today. In 1996, Adderall was approved as a treatment for ADHD by the FDA. In 1998, the American Medical Association stated ADHD to be one of the most researched disorders. However, there still is no cure.

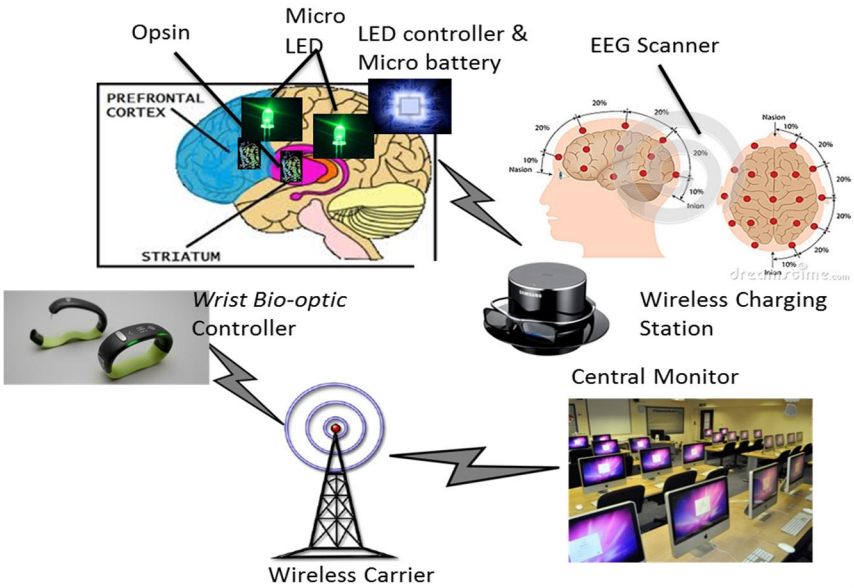
Future Technology

The *Bio-optic Surveillance System* is a device used to monitor ADHD symptoms in real time, and eliminate or alleviate such symptoms. By combining optogenetics, micro-

LEDs, electroencephalography scanning, wireless communication, and powerful wireless electricity, we can make a device that has the ability to detect and eliminate ADHD symptoms without drugs. The device controls ADHD symptoms by stimulating dopamine receptors in the prefrontal cortex and striatum to reverse the symptoms.

The heart of this device is a technology/science called optogenetics. Optogenetics was originated from Bio-X, a multidisciplinary project partly lead by Stephen Chu, who was a Stanford physicist[8]. They developed the idea from a certain kind of microbe containing a type of protein called an opsin. Such microbes can turn toward or away from the sun to regulate energy intake. When sunlight hits the opsin, it sends out electric signals that coincide with the signals used by neurons in our brain[8]. As a result, opsins can be used to activate or deactivate brain cells (neurons). Our device takes advantage of optogenetics to increase dopamine release, instead of drugs.

The device includes six major components, as illustrated in the diagram below.



References: [9] [10] [11]

The first component will be light sensitive opsins implanted into the brain to turn targeted neurons on or off, to allow optogenetics to be utilized in this device. The process starts with obtaining the opsins from sources such as algae and archaebacteria. The alga makes a protein called ChR2 that acts as a receiving end of blue light to activate neurons in the brain. In order to target only the dopaminergic neurons related to ADHD, snippets of DNA called promoters are applied to link the ChR2 with DNA found specifically in dopaminergic neurons[8]. The genes taken from the above steps are injected into retroviridae that have been emptied of their harmful content. The retroviridae are then injected into the brain[12]. The retroviridae would infect the targeted neurons in the prefrontal cortex and striatum, transferring the opsin gene to them. After this process, the neurons will be able to respond to light.

The second important part of this device is a series of micro-LEDs sized at one fifth of the width of human hair[13], which can be implanted into the brain permanently, using certain techniques well known to surgeons[14]. The micro-LEDs are small, yet can emit adequate light to activate the opsins in the brain. To implant it into one's brain, a micro needle and a biodegradable silk adhesive are used. The silk adhesive sticks the LED onto the needle, but the silk adhesive is water-soluble, such that the LED will remain in the head. The micro-LED is connected to a microchip LED controller.

The next object of interest in this device is a powerful but small energy source. A micro-battery that is as thin as a credit card, but also 2000x powerful than conventional batteries, is used in this device. This battery can also be charged 1000X faster within seconds, allowing this battery to be used at any time[15]. This battery can be charged in full wirelessly within a few seconds by magnetic field generator at home, at work or in

school[16]. The magnetic field is converted into electricity, yet it is strong and safe. Only objects vibrating at the same frequency will be affected.

The fourth component is the *Wrist Bio-Optic Wrist Bio-Optic Controller* that sends wireless signals to the microchip LED controller to control when to turn on which LEDs. This *Wrist Bio-Optic Controller* is a microprocessor in the form of a watch or wristband being attached to the patent's wrist. The microprocessor can match brain waves with pre-defined ADHD specific patterns and control the LED lights accordingly to bring the attention level back to normal. The *Wrist Bio-Optic Controller* has an emergency switch to turn off the device whenever unusual effects occur. This *Wrist Bio-Optic Controller* also has a cellular component connected to the mobile phone network. This cellular component enables the device to be linked to a hospital or a clinic. A professional monitoring the device remotely can also turn off the device when necessary.

The fifth component of this device is an electroencephalography [17] (EEG) scanner, which appears as a hat on the outside, but has electrodes connected to it from below. This allows the device to take the readings from underneath the "hat". One thing that the EEG scanner will be looking for is alpha and beta waves. Typically, children with ADHD will have a tendency to have poor alpha and/or beta wave suppression[18]. The EEG readings are gathered and sent to the *Wrist Bio-Optic Controller*. If the *Wrist Bio-Optic Controller* detects that the alpha and beta waves are abnormal, sends a signal commands the micro-LEDs to be turned on. In the case that the hat is not on the patient's head, the device will go into manual mode, in which a switch on the *Wrist Bio-Optic Controller* will be used to turn on the micro-LEDs when necessary, e.g. when trying to read a book but cannot be focused.

The last component is a remote monitoring system in a central monitoring center, like in a clinic or a hospital. These are complex computers with tremendous computing power and huge databases to record the massive amounts of data collected, and to use big data technology to perform data mining tasks, thus exploring more potential ways to cure ADHD. New LED controlling algorithms can be developed from data mining and then remotely sent to the *Wrist Bio-Optic Controller* patients wear via the cellular network.

Breakthroughs

Several breakthroughs are required for this device to work. First of all, for optogenetics technology to be allowed in the human body, it has to be approved by the FDA. Currently, this is only tested on animals. Also, in order to target specific neurons for precise control, scientists need to find more neuron types, their roles in the brain, and how they interact with surrounding parts of the brain. Currently we have very limited knowledge about which neurons are responsible for exactly what functions, and what side effects might occur if they are manipulated.

The second category of breakthroughs falls under ADHD diagnosis and detection. Current EEG scanners are clumsy and large, not portable at all. Without portable EEG scanners, the device cannot monitor the patient's brain waves in real time unless he/she sits with a fixed EEG scanner at all times.

The next category of breakthroughs concerns about the power source(s) of the device. Today's portable batteries are not powerful enough to provide all the power we need for the EEG scanner to function 24 hours a day non-stop. Other components, such as cellular transmitter and LEDs, also use large amounts of power. But large capacity

batteries today are usually heavy and clumsy, and take a long time to charge. If this device has to be connected to the wall, or needs frequent charging during the day, it will become impractical. This device also uses wireless charging, a technology that is not mature yet. Breakthroughs in wireless charging to make it efficient, quick, powerful and safe will be necessary.

Finally, the costs of the above technologies need to be significantly brought down from today's level in order for this device to be practical and popular. For example, doing one EEG scanning in a clinic costs a few hundred dollars in 2013[19], not to mention to purchase an entire EEG device.

Design Process

We considered many aspects of this device when doing this project. After we had the basic idea, we set about to decide on what parts to use. First of all, we had to decide how to get the light into the brain. The light source could have come from a laser outside and transmitted via an optic fiber, or have a micro-LED inside the brain to directly send the light. When we read the article describing the micro-LED, we found that the micro-LED was the most neuron-friendly way of delivering light into the brain[13], so we decided to use the micro-LED instead. While the LED is still in the lab, this light source has already been proven to work. This made us choose the LED, as it is very lightweight, cheap and proven. Also, the LED destroys less neurons than other methods of delivering light.

Next, we had to design *Wrist Bio-Optic Controller*. We thought about using a smart device like a watch or wristband, or microchips integrated into the circuit of the micro-LED. The microchip idea is ideal at the first glance. It integrates all functions into one

piece, and reduces communications between the LED controller and the *Wrist Bio-Optic Controller*. However, since we needs the *Wrist Bio-Optic Controller* to communicate with remote center with cellar signals, if is placed near the brain, it could be very damaging due to the strong radiation. The *Wrist Bio-Optic Controller* in the form of a watch or wristband would reduce the effects of strong EMR to the brain. Eventually we decided that safety is more critical, so we used the watch/wristband approach, even though this means an extra component to our overall design.

Next, we had to decide whether this device should operate automatically or manually. The automatic mode requires a component to monitor the ADHD behavior, and thus increases our research work and complexity of the device. The manual mode is simple: if the user feels that he/she ca not focus, he can turn on the device with a switch. We debated for a long time, and later decided that user convenience is critical for acceptance of this device. And also, the monitoring part gives us a lot of advantages for data gathering and analysis later. Thus we researched on the EEG technology and integrated it into our device.

The last decision we had to make is about the power source. One choice was to use wireless electricity, and the other was to use a small but super powerful battery that can be charged quickly. Both of these concepts exist today, but are still in the labs. While the wireless electricity concept looks attractive, we are afraid that there are places where wireless electricity is not available, such as in the subway. The decision was that we want to integrate both: a high capacity micro-battery, along with a wireless charger, to ensure that the device has enough power anywhere and anytime.

Consequences

There are quite a few consequences that would occur as a result of this technology.

First concern is the psychological impact on patients. ADHD occurs mostly in children, and unfortunately, children do not always accept others who are different. Wearing an EGG enabled hat sends a signal to peers that the child has ADHD. This may make him/her a subject of ridicule.

Second, there are some legal implications. Since this device manipulates the human brain, it leads to the question of who is to be held responsible for unexpected user behaviour caused by the device? Is it the person wearing the device, the doctor/psychologist prescribing the device, or the manufacturer making the device? And how do we determine which behavior is caused by the device, and not the free will of the patient?

Third, there are ethical implications as well: is it ethical to manipulate a human brain, and hence human behavior? What if this technology is abused to cause unwanted behaviors, or even full control of human brains? Does that break the United Nation's definition of human right of free will?

Fourth, there are also privacy concerns. Could the wireless network our device uses be hacked? Can the data on one's neural oscillations be used to track individual behavior and thoughts? Finally, there are also technical concerns. What would happen if the device malfunctions? What would happen if the battery runs out without charging? And what would happen when the device is turned on when ADHD symptoms are not obvious?

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A Video About Optogenetics & How It Can Be Used To Treat ADHD

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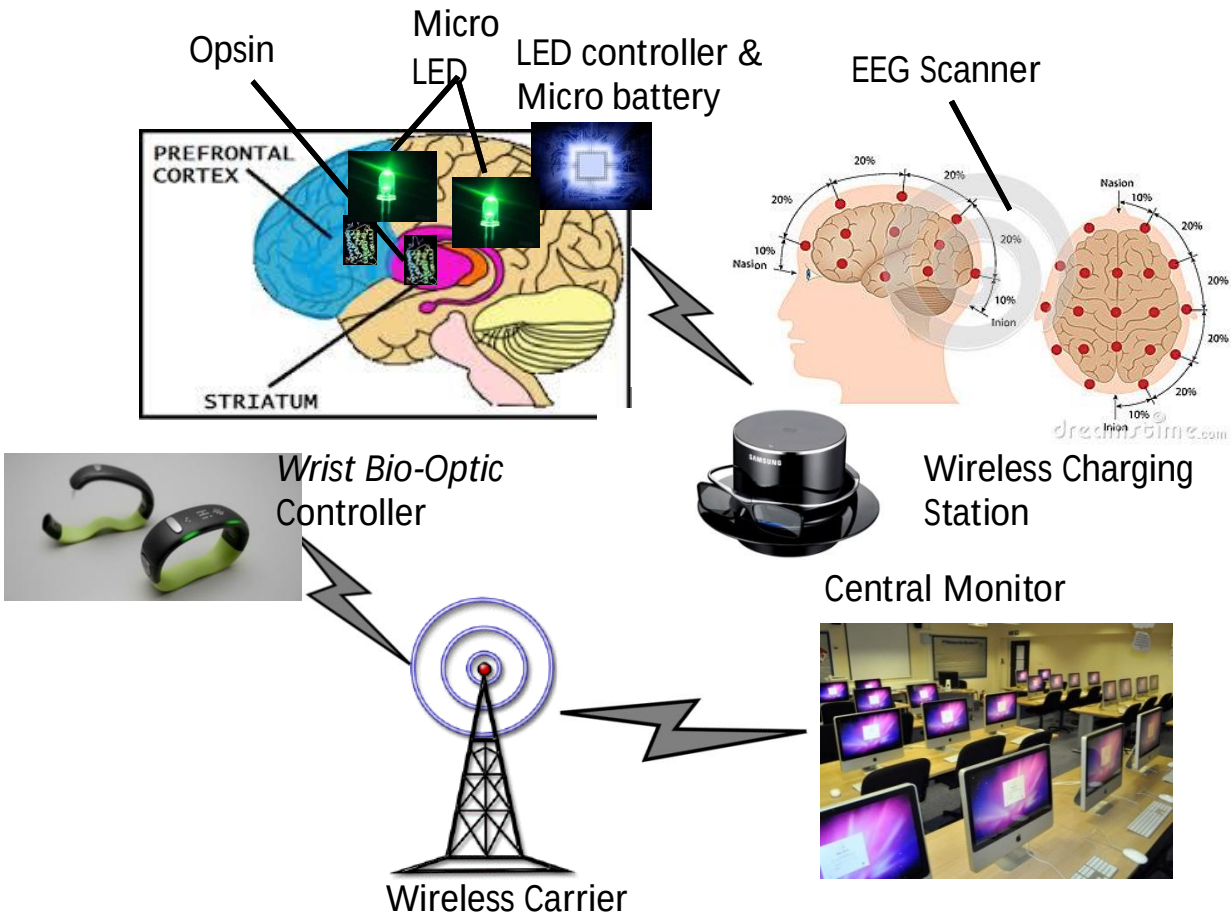
It utilizes optogenetics technology to control dopamine releases in the brain to revert or prevent ADHD symptoms. Light-sensitive proteins, called opsins, are injected and bound to neurons in prefrontal cortex and striatum area of a patient's brain. The now light-sensitive neurons can then be activated by the device to release dopamine, which supresses ADHD behavior.

The patient's brain wave is monitored by an electroencephalography scanner (EEG) in real time. When ADHD symptoms are detected, the device automatically turns on a micro LED that shines a specific spectrum of light onto the light sensitive opsins implanted, which in turn simulate human nerve cell signals to stimulate a release of dopamine. This process reverts ADHD symptoms.

Timeline:

- 1775: First description of symptoms similar to ADHD published by German physician and author Melchior Adam, in his book *Der Philosophische Arzt*
- 1902: ADHD first recognized as disorder. Cases of impulsive behavior recorded by Dr. Still. Named “Defect of Moral Control”. Believed to be a medical problem.
- 1922: ADHD diagnosed as “Post-Encephalitic Behavior Disorder”.
- 1937: Stimulants used to treat children with ADHD. Synaptol introduced by Dr. Charles Bradley
- 1956: Ritalin (another stimulant) is available to treat children who are considered hyperactive.
- 1960s: More stimulants are used to treat hyperactive children. Called "Minimal Brain Dysfunction" at start of decade, later changed to “Hyperkinetic Disorder of Childhood”
- 1970s: More symptoms are recognized, such as impulsiveness, lack of focus, and daydreaming. Impulsiveness is divided into the verbal, cognitive, and motor subtypes.
- 1980: Re-named “Attention Deficit Disorder” by American Psychiatric Association.
- 1987: Name revised to “Attention Deficit Hyperactivity Disorder” (ADHD)
- 1996: Adderall approved as a treatment for ADHD
- 1998: Stated by the American Medical Association to be one of the most researched disorders. However, there still is no cure. Until now …

- Medication
  - Stimulant drugs: increase release of dopamine, and slow the process of dopamine recycling. Works on 70% to 80% of patients.
  - Non-stimulant drugs: increase release of norepinephrine, longer lasting, smoother effect. But they upset stomach, decrease appetite, cause fatigue and dizziness.
- Drawbacks of current medication
  - The dosage is hard to measure: different ADHD patients react differently to dopamine, and even for the same person, the brain activity is different at different times.
  - Risk of drug abusing: There have been reports of people using ADHD stimulants that weren't prescribed for them. People have crushed and snorted Ritalin tablets, or dissolved the drug in water and taken it intravenously.
  - No accurate targeting: current medications have an effect of the entire brain. This causes unrelated circuitry in the brain to be affected, causing undesirable effects such as loss of appetite, sleep problems, and mood swings
  - Can not be monitored and controlled in real time. Patients get feedback only when revisiting their psychologists. There is no objective records other than verbally described feelings to be judged by the psychologist.



Six Components

Optogenetics (Opsins): light sensitive opsins are implanted into the brain to turn targeted neurons

- Opsins obtained from algae and archaebacteria
- Extract ChR2 protein from the opsin
  - Link DNA promoters from target neuron to CHR2
- Inject above genes into retroviridae
- Inject retroviridae to brain
- retroviridae infect targeted neuron, making them responding to light

Micro LED

- Size: one fifth of human hair
- Power: enough to activate opsins in the brain
- Using micro needle and a biodegradable silk adhesive to implant

LED controller & Micro battery

- LED controller is a microchip to receive signal from central controller and controls which LED to turn on
- Powered by a micro battery that is 2000x more powerful than conventional battery, and charge 1000x faster within 10 seconds

EEG Scanner

- Placed inside a hat
- Captures alpha and beta waves
- Sends readings to central controller wirelessly

OptiGen Controller

- Reacts to EEG collected brain wave
- Activate LED controllers wirelessly
- Sends collected brain wave to central

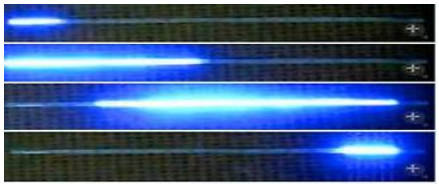
Central Monitor

- Remote monitoring
- Data analysis
- Remote software push

Real time 24 hours monitoring of ADHD symptoms

Micro battery with 24 hours continuous operation, and completely charged in 10 seconds

Automatically activated when ADHD symptoms are found



More Benefits

- Central monitoring by psychologist or doctors
- Remote diagnostics and software upgrades
- Precise targeting in brain without side effects

NOTE: above images extracted from:

- http://www.reachlocal.com/live-chat-old
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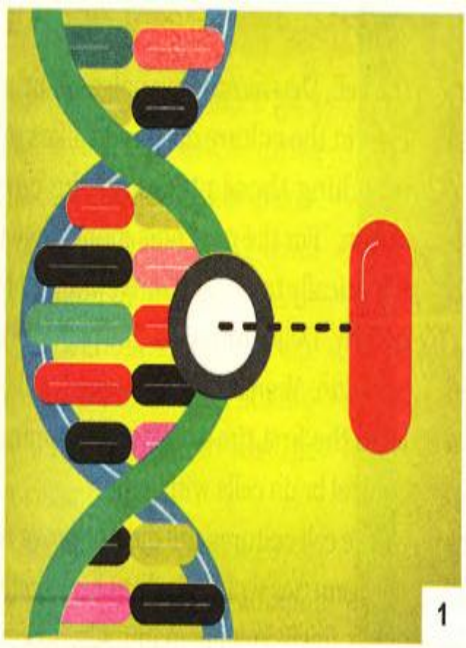
- Brain image, http://web.mit.edu/newsoffice/2013/possible-role-for-huntingtons-gene-discovered-0116.html
- Kids taking drugs image: http://articles.mercola.com/sites/articles/archive/2011/01/14/which-are-more-dangerous-alternative-medicines-or-prescription-drugs.aspx
- Wireless charging image: http://www.avforums.com/threads/samsung-ps51d6900-owners-thread-part-1.1438028/page-13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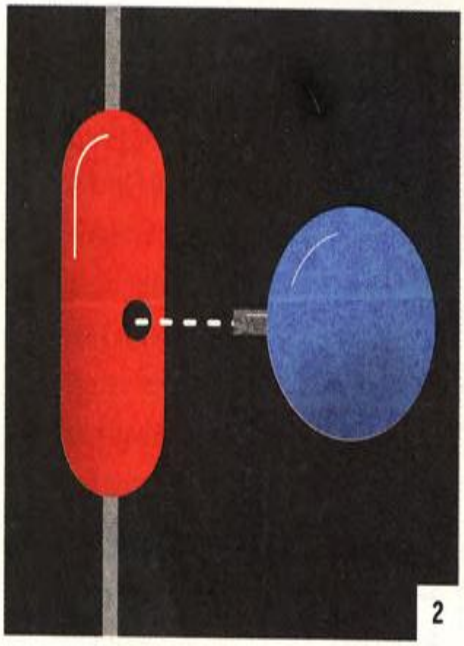
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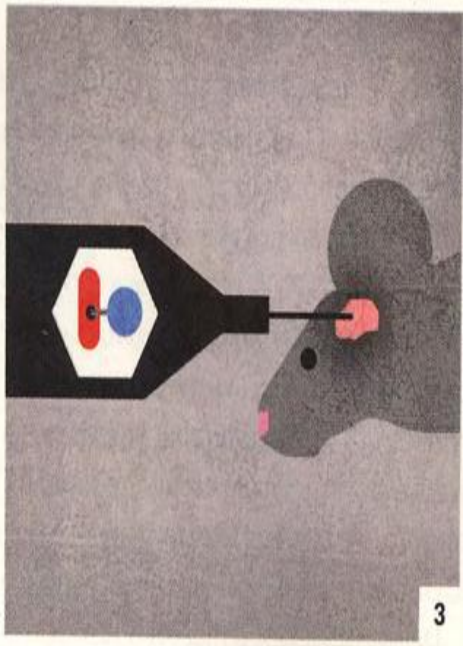
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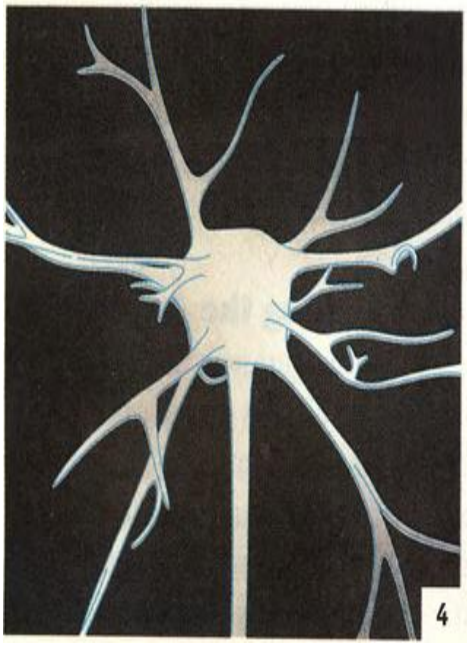
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