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Darius Witold Bieganski
Claremont McKenna College

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Claremont McKenna College

The Efficacy of Biofeedback and Its Use Towards ADHD

Submitted to
Professor Alison Harris

by
Darius W. Bieganski

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Darius W. Bieganski

Claremont McKenna College

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Abstract

Attention deficit hyperactivity disorder (ADHD) is a psychopathology commonly characterized by general inattentiveness and/or a lack of impulse control resulting in hyperactive tendencies. ADHD is estimated to cost the United States roughly $266 billion every year. ADHD is currently treated via medications, cognitive behavioral therapy, or more recently, neurofeedback. Neurofeedback – and biofeedback in general – is the process of providing a patient with information about autonomic bodily functions so that they may control said autonomic function. In the case of ADHD, neurofeedback focuses on reinforcing the behaviors and sensations associated with attentiveness. Currently however, neurofeedback systems are large and require a patient to travel to a clinic. Furthermore, the current offering of portable neuro/biofeedback devices do not have the technological capabilities to provide effective neurofeedback therapy. Current wearable tech devices – such as the Apple Watch and Samsung Gear – possess the technological capabilities to measure important bodily functions, and provide appropriate biofeedback therapy while remaining discrete and most importantly, portable.

Introduction

Attention deficit hyperactivity disorder (ADHD) is a psychopathology commonly characterized by general inattentiveness and/or a lack of impulse control resulting in hyperactive tendencies (Barkley, 2015). Associated with symptoms like daydreaming, forgetting, fidgeting, and squirming, ADHD can greatly interfere with a child's learning as well as an adult's productivity in the workplace. These behaviors have serious economic consequences: ADHD is estimated to cost the United States roughly $266 billion every year, 70% of which can be accounted towards loss of income and loss of work productivity for adults with ADHD (Doshi, 2012).

In the United States, 11% of children ages 4 – 17 and 4.4% of adults have been diagnosed with ADHD (Pastor, 2015). These numbers have been steadily increasing since the 1970s, due in part to changes in diagnostic criteria and to an increased availability and acceptance of treatment through medication (Barkley, 2010). Of the aforementioned $266 billion cost associated with ADHD, 10% arises from special services ranging from educational accommodations to visits to the physician, whereas 20% goes towards paying for medication (Doshi, 2012).

The costs of medication and associated services to treat ADHD can be particularly significant in the United States, due to the expectation that patients will shoulder the costs of health care. According to Doshi (2012), the average American is estimated to spend $1,105 out of pocket on pharmaceuticals and medical goods. This cost represents over 155% more than the combined average of all other nations in the data group. For ADHD, the breakdown per year on an individual level is estimated to include education costs of roughly $3,000 per person in a family, and medication and healthcare costs of roughly

$2,500 per person in a family. My personal experience as an individual with ADHD is illustrative of how quickly costs can increase. Every three months, I must pay $650 for a bottle of 90 pills. Every time I am prescribed these pills, I must go into my physician's office for a check-up, bringing the real cost of my prescription up to $1,250. In total per year, I spend $5000 on medication alone.

However, as the number of ADHD diagnoses continues to increase, concerns about the over-prescription of ADHD medication have been rising (National Institute on Drug Abuse, 2016). Typical medications for ADHD are stimulants that act on neurotransmitters in the central nervous system. Along with their high economic costs, the effects of prolonged use of these substances is unclear, especially for individuals with less severe symptoms and/or ongoing neurodevelopment (National Institute on Drug Abuse, 2016). For this reason, the American Psychological Association (APA) and Children and Adults with Attention-Deficit/Hyperactivity Disorder (CHADD) have identified a general desire and potential need to avoid prescribing drugs, especially to younger children. Together, the two organizations have conducted a series of studies identifying effective treatments for ADHD.

According to research by these organizations, cognitive behavioral therapy (CBT) is an effective alternative to medication in both individual and group settings (Barkley, 2010). However, the effectiveness of CBT is potentially limited in practice by the need for ongoing interactions with a therapist. Compared to the convenience of a pill that can be consumed anywhere at any time, maintaining a schedule of visits to the therapist may be a challenge, especially for individuals with attentional difficulties.

What is needed then is a method of providing the benefits and lasting effects of therapy, with the convenience of taking medication. Biofeedback – and more specifically neurofeedback – may provide the solution. Biofeedback is the process of measuring a subject's physiological processes, and visualizing the measurements so that the subject is aware of the physiological processes. Neurofeedback is a similar process involving neurological signals and processes instead of physiological signals and processes. Biofeedback and neurofeedback are relatively new fields having emerged in the last half century but are already used extensively to treat a variety of ailments both physical and psychological.

There are a few drawbacks to biofeedback and neurofeedback treatments; the biggest being transportability of treatment. To accurately measure and analyze brain signals, a large headset attached to a powerful desktop computer must be used, limiting the transportability of the system. Furthermore, because data is only collected when a patient is using a neurofeedback device, they must go to the clinician's office for repeated sessions in order to collect sufficient amounts of data. However, a there may now be a solution.

In the past 5 years, the consumer tech market has witnessed an explosion of "wearable tech". Wearable tech is the term used to refer to any portable electronic device that is worn on the body such as a watch or glasses. These devices come with a variety of sensors built in with the purpose of measuring bodily functions including heart rate, blood oxygen levels, activity levels (steps taken, minutes spent exercising, etc.), and sleep patterns/quality. Currently, wearable tech is used to promote consumer health and a healthier life style, but the sensors and technology employed is underutilized.

This poses the question: can wearable tech devices be used as a biofeedback device for a *psychological* disorder such as ADHD? The purpose of this thesis is to critically evaluate the data regarding biofeedback treatments and compare it to conventional treatments. If biofeedback and neurofeedback are both found to be effective treatments, then a proposal on how to employ wearable tech for the treatment of ADHD will be given.

Biofeedback

Biofeedback is the process of measuring a subject's physiological processes, and visualizing the measurements so that the subject is aware of the physiological processes (Durand, Barlow, 2009). Biofeedback relies on physiological recording techniques that are typically electrical in nature: electromyography, electroencephalography, and electrocardiography. These methods were originally developed in a clinical setting and are used to measure various physiological phenomena within the body.

Electromyography (EMG) is used to record the electrical activity produced by skeletal muscles (Tassinary, 2007). This is achieved by measuring the overall electric potential generated by cell muscles which, is measurable through a subject's skin. Various muscular ailments are treated today using EMG biofeedback. One such ailment is Spastic Pelvic Floor Syndrome (SPFS). Spastic pelvic floor syndrome (SPFS) is a functional disorder of the pelvic floor muscle wherein during straining, the muscle contracts instead of relaxes, causing a functional rectal outlet obstruction (Dickinson, 2006). Prior to EMG biofeedback, SPFS was commonly treated with laxatives and water enemas. Repeated use of such devices can leave lasting damage internally. The key

feature of the treatment is that a patient relearns normal, autonomous muscle functioning (Barnett, 2014).

When a subject's floor muscle is straining, their EMG measurements read 70+ microvolts; conversely, when a subject's floor muscle is relaxed, their EMG measurements read >20 microvolts. While observing his/her EMG measurements in real time, a patient focuses on the sensation of his/her contracting muscles. Then, the patient must think about lowering the EMG levels, and focus on the muscle sensation that follows. As the patient focuses on the EMG read out, his/her muscles will contract or uncontract accordingly. The EMG read out allows the patient to observe, process, and control bodily signals that they were unable to process prior. In the case of SPFS, it is processing and controlling the signals between the brain and pelvic floor muscle. Furthermore, through repeated sessions, a patient can relearn control of a given muscle without the aid of an EMG readout, having relearned how to process his/her bodily signals.

EMG biofeedback is only one of the three major biofeedback recording methods. Electrocardiography (EKG) and electroencephalography (EEG) are used in a similar manner when working with the heart and brain respectively. The major impact of biofeedback is that it is psychological in nature. Biofeedback does not require the use of medications or special medical procedures; all that is required are non-invasive sensors placed on the patient's skin. Starting in 1958 – when Dr. George Mandler proved the existence of a link between psychological and physiological reactions – hundreds of studies have proven the efficacy of biofeedback in treating a variety of physiological and psychological pathologies (Thatcher, 2015).

In 1865, Claude Bernard proposed the theory of homeostasis. Homeostasis states the human body will actively regulate bodily functions to maintain a state of constant being. The theory stated that each bodily function was regulated and controlled by a biological mechanism known as a homeostat. Bernard proposed that if a person was able to control a homeostat, they would have voluntary control over the corresponding bodily function (Bernard, 1957). Twenty years later, Ivan Tarkhanov, a Russian physiologist most known for his discoveries in the heart and circulatory system, demonstrated that voluntary control of one's heart rate was relatively easy through simple concentration on the sensation of the beating heart (Tarchanoff, 1885). At the time, the discovery remained little more than a scientific amusement.

The next major step in the establishment of biofeedback as a legitimate field of study came in 1958. Austrian scientist George Mandler conducted an experiment regarding autonomic self-perception, the awareness of one's automatic physiological responses; i.e. sweating when stressed, crying when sad, hyperventilating when scared. Mandler was specifically interested in the relationship between the severity of autonomic reactions to one's awareness of autonomic reactions (Mandler, 1958). Using a self-assessment questionnaire and an interview, Mandler found 14 subjects (Group A) with high autonomic reaction scores and 9 subjects (Group B) with low autonomic reaction scores. Subjects from both groups were then placed in high-anxiety situations – difficult paper exams, scary movies/images – while their autonomic reactivity was measured via heart rate, psychogalvanic response, respiration, face temperature, and blood pressure. Subjects were then asked to self-report their own perceived stress level as well as their own perceived autonomic response level. Mandler's results showed there was a positive

correlation between a subject's self-reported response levels and their observed response levels (Mandler, 1958). Furthermore, the results revealed that subjects with a high level of responsiveness almost always overestimated their stress levels while subjects with a low level of responsiveness almost always underestimated their stress levels. The results demonstrated two things. First, the results demonstrated a link between psychological and physiological reactions. Second, and more importantly, the results suggested that if a subject could control their autonomic responses, they could control their psychological responses.

4 years later in 1962, Donald W. Shearn, an American scientist conducted an experiment to determine if a subject could control their heartrate. Shearn took 46 undergraduate male volunteers and provided each subject with a heartrate monitor. Over the course of 20, 30 second trials, each subject was asked to attempt to raise their heartrate without the use of hyperventilation. If the subject didn't successfully raise their heartrate they were given a mild shock. Results showed that with each session, the number of times a subject could raise their heartrate increased (Shearn, 1972). Furthermore, the results showed that if a subject was given less time before the shock, they were still able to adapt and rapidly increase their heartrate voluntarily. The results of this experiment demonstrated that it was possible to control one's heartrate by simply watching a heartrate monitor. Furthermore, the results This was the first recorded use of modern biofeedback.

Despite Shearn's discovery, his experiment wouldn't be peer-reviewed until a decade later in 1972 with the release of the 'Handbook of Psychophysiology'. The peer review included a replication of Shearn's experiment, conducted by Thomas McCanne

and Curt Sandman (Dawson, 2007). The experiment involved twelve healthy male volunteers from an undergraduate psychology class. Like Shearn's study, each subject was presented with a heartrate monitor. McCanne and Sandman's experiment focused on a few methodological concerns.

The first method change was that each subject would be asked to both accelerate and decelerate their heart rate. McCanne and Sandman were interested in the possibility of different psychological mechanisms involved in learning how to accelerate and decelerate one's heartrate. The second method change was that each subject would go spend a week conduction sessions instead of a few minutes total. Specifically, each subject would spend five consecutive days with 10, 30 second sessions each day. The purpose of this change was to determine if control of autonomic physiological functions could be learned. The results of the experiment revealed that not only indeed could a subject control an autonomous function such as their heart rate, it became clear that the subjects had learned how to accelerate and decelerate their heart rate by the end of the trial, having learned how to do so throughout the week of tests (Dawson, 2007). A demonstrated and proven ability to learn physiological and psychological self-control meant that psychological therapies could be used in lieu of drug-based therapies for physical ailments.

In 1976, the Biofeedback Society of America was established – know known as The Association for Applied Psychophysiology and Biofeedback – with the goal, as stated by the AAPB, is to "promote a new understanding of biofeedback and advance the methods used in this practice." Soon thereafter, the AAPB researcher John Basmajian published *Biofeedback: Principles and Practice for Clinicians* (Basmajian, 1979). The

purpose of Dr. Basmajian's publication was to serve as a central source of knowledge regarding then-current biofeedback techniques. One particular field of interest was musculoskeletal manipulation of normally autonomous processes; a form of electromyographic biofeedback (EMG).

As the medical community's understanding and acceptance of biofeedback grew, the understanding and acceptance of neurofeedback grew as well. Neurofeedback, much like biofeedback, is the attempt to manipulate normally autonomous mental functions through the observation of physiological brain-wave readings. The primary area of treatment that neurofeedback is aimed at is psychopathologies. In 1994, the AAPB established a dedicated research group for brain-wave feedback as well as a dedicated research group for EMG feedback.

That same year, the EMG group published an experiment focusing on the efficacy of biofeedback in regards to stress and pain management. The experiment – conducted by Dennis C. Turk, Hussein S. Zaki, and Thomas E. Rudy – involved 80 subjects suffering from temporomandibular joint dysfunction (TMD) (Turk, 2002). The 80 subjects were randomly assigned to one of three groups. The first group (Group A) would receive traditional oral painkillers and would be asked to rate their pain levels following treatment. The second group (Group B) would receive a biofeedback-based stress/pain management treatment. Group B was shown a collection of biofeedback readings consisting of skin conductance, heart rate, blood pressure, and EMG readings of the jaw muscle. Subjects in Group B would be asked to focus on lowering the biofeedback readings while remembering the sensation of the lower pain levels. The third group (Group C) was a control group and didn't receive any treatment. The results indicated

that subjects in Group A experienced higher levels of relief than subjects in Group B following treatment. This was partially to be expected given that TMD is the inflammation of the jaw joint. Following the initial experiment, a 6-month follow up was conducted to determine how the subjects' pain management has progressed. Subjects in Group A severely relapsed in pain management, a majority of the subjects still relying on pain medication. Subjects in Group B, however, showed a marked improvement in their pain management and comfort. Furthermore, a repeat experiment was conducted where 30 subjects were given both oral painkillers and biofeedback-based treatment. This group showed better improvement than either Group A or Group B, using pain killers for early relief and transitioning to psychological methods of pain management (Turk, 2002). The results of this experiment were important because it was one of the first times that biofeedback had been used to manage pain rather than a specific muscle function. This was one of the first large steps towards the validation of meditation and thought therapy as a useful medical tool for patient pain management.

ADHD & Neurofeedback

ADHD is a psychopathology commonly characterized by general inattentiveness and/or a lack of impulse control resulting in hyperactive tendencies. The Diagnostic and Statistical Manual, 5th Edition (DSM-5) categorizes the symptoms of ADHD into two categories: inattention, and hyperactivity and impulsivity. There are three presentations of ADHD that can occur based on the symptoms present in an individual; they are as follows: ADHD-Predominantly Inattentive, ADHD Predominantly Hyperactive-Impulsive, and ADHD Combined. The symptoms associated with ADHD can interfere

with a child's learning as well as an adult's productivity in the workplace. For example, an individual with ADHD-Predominantly Inattentive (such as this author), will often have trouble holding attention on tasks, won't seem to listen when spoken to directly, and often loses things necessary for tasks and activities such as eyeglasses or cell phone. In contrast, individuals with ADHD Predominantly Hyperactive-Impulsive will often fidget and squirm when seated, have trouble staying seated for extended periods of time, and talk excessively or out of turn. In order for an individual to be diagnosed with ADHD, he or she must not only display 6 or more symptoms, but there must also be clear evidence that the symptoms present interfere with, or reduce the quality of, social, school, or work functioning. The symptoms present must also be deemed inappropriate for the age or developmental level of the individual in question (American Psychiatric Association, 2013).

The exact cause of ADHD is unknown, but there are several risk factors that can contribute to the development of ADHD. If a blood relative, such as a parent or sibling, has ADHD or similar psychopathology, an individual will be more likely to develop ADHD. Maternal drug or alcohol abuse as well as premature birth are both identified risk factors in the development of ADHD. ADHD shares a co-morbidity with several other psychopathologies including depression, bipolar disorder, Tourette Syndrome, and general anxiety disorders (Kessler, 2006). Each of the listed psychopathologies – including ADHD – can be characterized by a chemical imbalance in the brain; more specifically, an imbalance of key neurotransmitters (American Psychiatric Association, 2013).

At the neural level, individuals with ADHD are often described as being in an un-aroused state (Bakhshayesh, 2010). Critically, the ADHD brain shows measurably lower levels of one of two specific neurotransmitters: dopamine or norepinephrine. ADHD Hyperactive-Impulsive is associated with lower levels of dopamine, which is involved in the regulation of reward-motivated behavior, emotional responses, and motor control. Consistent with the role of dopamine in motor control, symptoms associated with ADHD Hyperactive-Impulsive include constant fidgeting or vocal outbursts (Daly, 2015). Due to dopamine's role in reward-motivated behavior, symptoms also include general impatience and a desire to complete a task using minimal effort, often at the cost of quality (Barkley, 2015). Lower dopamine levels associated with ADHD Hyperactive-Impulsive can also be observed as emotional immaturity. Individuals with ADHD Hyperactive-Impulsive are often characterized as having difficulty maintaining relationships both intimate and not (Goldstein, 2000).

ADHD Inattentive is marked by reductions in norepinephrine levels. Norepinephrine is responsible for promoting vigilance, formation and retrieval of memory, and focusing attention. Consistent with norepinephrine's role in vigilance, symptoms associated with ADHD Inattentive include being easily distracted and difficulty following through on instructions (Prevatt, 2015). Due to norepinephrine's role in memory formation and retrieval, symptoms also include difficulty remembering items in a short amount of time as well as difficulty remembering items without an external aid in the form of notes (Prevatt, 2015).

In all three subtypes of ADHD, the imbalance of neurotransmitters means that neuronal connections are weaker. The weaker connection – and imbalance of

neurotransmitters – is attributed to overactive neurotransmitter transporters. Neurotransmitter transporters are proteins found in the cell membrane of a neuron. The transporters are responsible for moving neurotransmitters across the cell membrane to change the neuron's cell potential and in turn trigger an electrical signal: the neuron firing (American Psychological Association, 2013). The transporters in an individual without ADHD only move neurotransmitters across the cell membrane when necessary, building up a ready supply of neurotransmitters ensuring that the action potential can be quickly triggered. In an individual with ADHD, the transporters are overactive. An overactive transporter moves neurotransmitters across the cell membrane too frequently which, in turn deprives the neuron of a neurotransmitter reserve. Specifically, an overactive transporter will move neurotransmitters outside of the cell, inhibiting the reuptake of neurotransmitters (Pedraza, 2015). By depriving the neuron of an available supply of neurotransmitters, more time is required to trigger the action potential, slowing down the entire signal chain.

This delayed neural firing can manifest itself in different behaviors—again, depending on the ADHD subtype. In the case of ADHD Hyperactive-Impulsive, a lack of dopamine and slower firing neurons can appear in a patient, for example, as a delayed impulse control or inability to wait their turn. A lack of norepinephrine and slower firing neurons in ADHD Inattentive can appear in a patient, for example, as an inability to quickly memorize information or propensity to misplace items (Pedraza, 2015).

There are two commonly accepted methods of treatment for ADHD. One is to increase dopamine and norepinephrine levels in the brain to compensate for the overactive transporters. The second is to inhibit the transporters so fewer

neurotransmitters are moving across the cell membrane. Currently, there are two classes of medications available: stimulants and non-stimulants (American Psychological Association, 2013). Stimulants and non-stimulants are used to treat both ADHD Hyperactive Impulsive and ADHD Inattentive; whether simulants or non-stimulants are used is dictated by the treatment method used. Both types of medications allow a patient's neurons to build up a neurotransmitter reserve, ready to be moved across the cell membrane when necessary (American Psychological Association, 2013). The availability of neurotransmitter reserves is reflected in reduced neurotransmitter

Standard medications provide a subject's brain with the means to produce the needed neurotransmitters which, in turn allows the neurons to fire more rapidly due to the reduced time required to build up neurotransmitters. By increasing the rate of neuronal communication, these drugs allow the individual to function "normally"; i.e. no longer engage in or display disruptive symptoms. However, neuronal communication is enhanced for only as long as the medications last; once the medication has run its course, the subject's brain is no longer able to facilitate improved neuronal connections. Furthermore, as with any drug, tolerance will build up over time, requiring higher and higher doses for the medications to remain effective. To combat the need for higher doses, subjects are often taught certain psychotherapies or coping methods that naturally facilitate improved neuron communication; methods can include frequent exercise/time outside, avoiding unhealthy foods, and taking frequent notes. Patients might also engage in cognitive behavioral therapy (CBT) which trains a patient to identify problematic behaviors and how to manage said behaviors (Pedraza, 2015).

Behavioral intervention – or cognitive behavioral therapy (CBT) – helps patients recognize patterns or problem behavior so that they better manage the identified patterns (American Psychiatric Association, 2013). Furthermore, parents and teachers will be given strategies to cope with disruptive behavior as well as address problematic behavioral habits at home and at school. Per a series of studies conducted by CHADD and the APA, CBT was found to be effective in both an individual and group setting. In all but one of the studies, CBT yielded significantly improved behavioral patterns and habits in the subjects (Pedraza, 2015). When CBT was used to help subjects improve their behavioral habits and patterns, subjects felt that they were being helped and that their "normalcy" was being reaffirmed (Gevensleben, 2012). CBT is a broad term and can be achieved through a variety of settings. A therapist or "life coach" can be considered a form of CBT as well as meditation and/or yoga.

But why does CBT work? CBT works because the subject is made aware of their behavioral habits. The subject is effectively trained to realize when he/she is engaging in a behavioral habit and what must be done in such an event. What makes CBT truly effective however, is the fact that there is a trained professional with the subject making them aware of their own habits. Once the subject is on their own, they are less likely to be aware of their behaviors and furthermore will be more likely to regress in their behavioral management techniques. Much like medication, the subject is still reliant on treatment to aid in their behavioral management (Gevensleben, 2012). Unlike a pill, therapists cannot travel with the subject to aid in correcting behavioral habits. If a therapist cannot travel with the subject, feedback needs to be provided to the subject via another method.

Without psychotherapy or medications (or a combination of both), a subject is unable to facilitate improved neuronal communication.

The aim of neurofeedback is to give subjects the ability to facilitate improved neuronal communication without the aid of medications or psychotherapy (Lofthouse, 2011). Neurofeedback relies on the principle that a subject's arousal (attentiveness) is dependent on the pattern of neural oscillations with the brain. Neural oscillation is repetitive neural activity within the brain. A single neuron repeatedly activating is said to be oscillating or displaying oscillatory activity. On a single-neuron scale, the oscillations appear as oscillations in the membrane potential. At the level of neural ensembles – groups of neurons activating in synchrony – the synchronized oscillations are measurable through the scalp using an electroencephalogram (EEG) and appear as signal frequencies, or brain waves.

There are four well-studied brain wave levels: delta, theta, alpha, beta. Delta waves range from 0.5 to 3.0 Hz and are present only when a subject is engaged in deep sleep. Theta waves range from 3.0 to 8.0 Hz and are present during light sleep and when a subject is awake but inattentive. Alpha waves range from 8.0 to 13 Hz and are present during any waking moment, and will disappear during moments of attentiveness. Beta waves range from 13 to 22 Hz and are present when a subject is alert, attentive, or engaged in various high level mental thoughts (Lofthouse, 2011).

As in biofeedback, a representation of the measured brain signals is shown to the subject for the purpose of teaching the subject to learn to regulate their brain activity. The brain signal representation often takes the form of a video game (Monastra, 2008). When a subject's brain wave activity indicates arousal and attentiveness – meaning their brain is

producing beta waves – the subject is given positive feedback. With this system, subjects are not only trained to regulate their brain activity, but are also trained to be more perceptive of how an attentive brain feels (Schummer, 2013).

However, it remains an open question how well neurofeedback works. Various clinical studies have been conducted to determine the efficacy of neurofeedback. In any study regarding ADHD severity, a battery of tests is used. The Test of Variables Attention (TOVA) is a neuropsychological assessment that measures a subject's level of attentiveness while simultaneously screening for ADHD. The test is typically presented as a simple and repetitive game on a computer. The test is meant to measure a subject's response to auditory and visual cues. A high TOVA score is indicative of an alert and attentive subject while a low TOVA score is indicative of a non-attentive subject (American Psychiatric Association, 2013).

Another test used to diagnose ADHD – among a variety of learning disabilities – is the Wechsler Intelligence Scale for Children (WISC). The WISC measures verbal comprehension, visual spatial skills, fluid reasoning, working memory, and processing speeds. The test is presented as a combination of verbal exams and paper exams. Along with the WISC, there is the Wechsler Adult Intelligence Scale (WAIS) (American Psychiatric Association, 2013). Like the WISC, the WAIS is a diagnostic tool used to measure intellect and cognitive ability in adults. The WAIS measures the same variables as the WISC, but uses different prompts that are more suited for adults and older adolescents.

Another commonly used diagnostic tool is the D2 Test of Attention. The D2 Test of Attention is a neuropsychological test meant to measure selective and sustained

attention of a subject. On a piece of paper, a subject must be able to find and highlight specific letters – usually the letter "d". The object of interest is placed among distractor objects that have a similar shape – in the case of the letter "d", each letter could be surrounded with "p" or "q" (American Psychiatric Association, 2013).

All the tests discussed have been translated and are used world-wide. Due to the tests' common use in diagnosing ADHD, studies involving ADHD and behavioral issues will use these three tests along with peer interviews to measure the severity or change in ADHD for any given subject (American Psychiatric Association, 2013).

The results pertaining to ADHD and neurofeedback have all been generally positive. In a study looking at the efficacy of EEG neurofeedback in training various ADHD coping strategies, children and adolescents (ages 8-19) participated in a 3-month long program of intensive neurofeedback training where reward was dependent on maintaining high beta-wave levels while avoiding theta waves (Lubar et al., 1995). Following the 3-month program, almost all subjects demonstrated improved TOVA scores, behavioral ratings, and better WISC-R performance. More importantly, these improvements were comparable to those of a subject on traditional medications (Lubar et al., 1995).

A similar study was conducted to compare the efficacy of EEG neurofeedback to the efficacy of traditional medications; in this case, methylphenidate. 22 children (ages 8-12) participated in a 3-month long program of intensive neurofeedback training while 12 children (ages 8-12) were given methylphenidate over the same 3-month period (Fuchs et al., 2003). Following the 3-month program, both groups demonstrated improved d2

Attention Endurance Test scores and behavioral ratings from parents and teachers. These results demonstrated that EEG neurofeedback was as effective as medications.

In one study, 100 children and teens with ADHD (ages 6-19) were given a variety of treatments, including medication, school consultation, and parent counseling (Monastra, 2002). Half of the children received this regimen while the other half received this regimen along with EEG neurofeedback training. After a year of treatment, both groups stopped taking the medication and measurements were taken a week later. TOVA and behavior scores for children who received neurofeedback were found to be in the "normal" range, or not indicative of ADHD. The scores for children who did not receive biofeedback were in the "clinical" range, or indicative of ADHD. Furthermore, children who did not receive neurofeedback started to exhibit ADHD symptoms just a week after not taking medication and sooner in some cases (Monastra, 2002). This study demonstrated that neurofeedback is not only an alternative treatment, but is an additive treatment in the presence of traditional treatments.

Despite its demonstrated efficacy and success in treating ADHD, neurofeedback still has flaws, some more glaring than others. While neurofeedback eliminates the need for medication, a subject won't necessarily pay any less than before. On average, a single neurofeedback session costs anywhere from $50 to $125 and in order for neurofeedback to be effective, a subject must undergo 30 to 40 sessions each lasting 2 hours; these are all the costs AFTER a subject has seen a psychiatrist and physician (Gevensleben, 2012). Furthermore, due to the novel nature of neurofeedback, many insurance companies view neurofeedback as experimental, and will not cover the costs. The bulk of the cost for neurofeedback treatment is in the time spent at the clinic. Whilst small, portable

consumer brain-reading devices have been on the market for almost a decade now, these devices have been little more than toys, incapable of getting the accurate measurements required for neurofeedback treatment. The devices required for neurofeedback treatment cost upwards of $25,000.

What is needed then is a portable device capable of making accurate, reliable, and usable measurements. More importantly, a device that is discrete is required. The success of non-medication-based treatments of ADHD, such as CBT, hinge on the subject feeling "normal" despite their disorder. Brain-reading devices, both consumer and non-consumer are large and ungainly by nature; even the latest consumer device, the MUSE, is a wide headband that covers a large part of the user's forehead and sides of their head. A subject feeling such a device will not appear as normal and thus most likely will not feel normal.

Proposed Device

As described above, the development of an effective biofeedback device for ADHD faces key challenges, including portability, accuracy, and discretion. In this section, I will review existing devices that have been developed to address these criteria, as well as assessing the technological capabilities of consumer wearable tech and how consumer tech could be used as a clinical biofeedback device. Based on this analysis, I conclude that no currently available device fully meets the needs of the ADHD population. Instead, I propose that rather than developing a bespoke device, current consumer wearable tech be repurposed to provide clinical biofeedback through means of a bespoke app capable to using the technology found in wearable tech.

In cooperation with several pharmaceutical companies – including Shire, the makers of Adderall – the APA has designed and validated several biofeedback-based CBT computer programs. While using the CBT program, the subject's neurological processes are recorded using an EEG cap so that the program may provide guidance accordingly. Much as a therapist would, these programs provide a subject with self-regulation techniques and exercises. Data suggest that CBT computer programs are successful in treating ADHD (Janessen, 2015). This success stems in part from the fact that the programming allows the recording device to act on the recorded data. However, like a therapist, computers capable of running CBT programs are restricted in movement and typically only exist on desktop systems. Although devices for neurological monitoring are themselves portable enough for a subject to use on a regular basis *and* cost little more than a single drug prescription, these monitoring devices do little else than record data. Even the most advanced portable recorder produced by the leading biofeedback device manufacturer (Current Technology Inc., Minneapolis, MN) lacks programmable logic, the ability to run any sort of on-board data analytics. Therefore, what is needed is a data recording device capable of data analytics—a portable computer. To address this issue, several biomedical companies have released apps and proprietary devices that together can perform a wide variety of tasks. However, on their own, each device is highly specialized, providing information pertinent to one or few

Thanks to advancements in modern computing, though, most of the population has access to a portable computer, in the form of a smartphone. Smartphones are incredibly powerful devices – the iPhone is more powerful than the computer on Apollo 11 – that can be connected to any number of devices. These devices include headsets,

cars, and most importantly, bio recording devices. As smartphones continue to advance, a new market has emerged which might provide a universal biofeedback device: wearable tech.

Wearable tech was introduced to the consumer market with the release of the Fit Bit in 2007. The Fit Bit is marketed as an activity motion tracker capable of counting a subject's steps, measuring their heart rate, measuring their blood-oxygen levels, sleep schedule, and exercises performed (FitBit, 2016). Furthermore, the device acts as a communication device for the phone, allowing a user to talk on the phone and reply to texts without needing to directly access the smartphone. The Fit Bit device itself is worn on the subject's wrist and is smaller and lighter than most watches. Since the introduction of the original Fit Bit, the wearable tech market has grown to a nearly $14 billion industry with 60 million devices being sold each year (Statista, 2016). Major consumer electronics companies including Apple and Samsung have entered the market with well-known devices such as the Apple Watch and Samsung Gear. Thus, wearable tech devices have the benefit of already being a popular technology, eliminating the need to create bespoke sensors and devices.

However, despite the popularity of wearable tech, their location on the body (e.g., wrist) limits their capabilities to motion tracking and blood flow monitoring. Although head-mounted technologies such as virtual reality are receiving new attention (Statista, 2016), to date no neurological recording device has been designed for discreet, portable day-to-day wear. This means that for a wearable-tech device to be successful, it must be possible to monitor a psychological disorder using these types of physiological measurements.

In the case of ADHD, existing technologies have instead focused on directing the user's attention towards specific reminders and tasks. Currently, there are a number of wearable devices on the market that are designed to aid in directing a user's focus, including the WatchMinder and T.Jacket. The WatchMinder (WatchMinder, 2016) is a small watch-life device that allows a user to create discreet cues throughout the day that remind them to perform specific tasks. These tasks are determined by the user, but examples include a child receiving notifications of when to take medications, or an adult being reminded of an upcoming meeting at work. Similar functionality is provided by other wristband devices such as the Re-vibe and Sqord (FokusLabs, 2016) (Sqord, 2016).

Another similar device is the T.Jacket. Similar to the WatchMinder, the T.Jacket provides discrete reminders to the user to perform certain tasks. However, unlike the WatchMinder, the T.Jacket (as the name implies) is a jacket-like piece of clothing that the user wears. The reminders are delivered via pressure applied by the jacket (imagine a hug) and can be remotely delivered by a parent or caretaker if necessary (TWare, 2016).

Despite their prevalence on the market, these devices suffer from major flaws, including requiring user input, being subject to habituation, and lacking awareness of the user's physiological state. First, the current offering of devices requires that the user set up reminders, which limits the functionality to dealing with events or tasks that are already scheduled. Furthermore, because most of these devices don't have a screen, they rely on the user to remember what the task in question is. When dealing with psychopathologies that affect memory, such as ADHD, this can lead to obvious problems. Worse, most current smartphones already come with reminder systems that have equal or greater capability. For example, both the iPhone and Samsung Galaxy can

deliver reminders based on a variety of conditions beyond time – location, whom the user is talking to, current activities – as well as delivering reminders just as discreetly.

This style of schedule or task reminder also suffers from habituation. As with medications, it is possible for users to build a "tolerance" to the reminders, especially if they are time-based (Thatcher, 2015). Over time, the user will learn to anticipate the reminders, and depending on the task, could begin to intentionally ignore the reminder. This is especially the case when children must take medications at specific times (Schummer, 2013). Furthermore, none of the current devices can deliver "context dependent" reminders. A context dependent event is an event that will only occur when certain criteria are met. In terms of reminders and scheduling, a context dependent reminder is a reminder that will only appear when necessary. For example, a child that needs to take medications at a specific time while at school won't want to receive reminders while on vacation or during the weekend when taking medications isn't necessary.

It is important to note that reminders are not detrimental or useless to those with ADHD; quite the opposite in fact (Salomone, 2012). However, reminders do not serve a therapeutic purpose. Reminders are simply another tool for those ADHD to rely on, and do not aid in the memory formation or recall necessary to remember tasks and instructions. What is required is a therapeutic device that responds not simply to time or location, but also responds to the current task at hand and most importantly, the current focus level of the user. As stated earlier, the device I am proposing wouldn't be able to measure brain activity; it must rely on physiological measurements representative of the user's attentiveness.

Current wearable tech can detect what type of motion or exercise a user is performing based on the measured wrist motions and accelerations. Furthermore, wearable tech – using the same methods – can determine a user's body position or stance and provide feedback accordingly. It stands to reason that this technology could be repurposed to detect when a user is attentive or inattentive. Studies conducted in the last year suggest that there is indeed a body position associated with attentiveness and a body position associated with inattentiveness; most importantly, the body positions are measurably different from each other. However, the specific details of the body positions are still debated.

One study involving 110 adolescents (13 – 17 years old) with ADHD Combined measured each subject's body position and movements during times that required focus (Cheung et al., 2016). Data was collected over the course of six years. The study revealed that subjects who were focused would almost always engage in a "preparation-vigilance measure". A preparation-vigilance measure, per the study, was a biomarker that was closely correlated with higher levels of attention. In this case, the preparation-vigilance process varied from subject to subject, but followed a similar pattern: prior to focusing, the subject would engage in a pattern of deep breathing, shaking out their arms, or a closing their eyes for a moment. Subjects who didn't engage in a similar activity almost always exhibited lower levels of attentiveness and awareness. Results also suggested that subjects who continued to engage in preparation-vigilance processes were more likely to experience a remission in their ADHD and associated symptoms (Cheung et al., 2016).

Deep breathing and shaking of the arms can both be detected using current market technology. The breathing could be detected via a sudden change in heart rate and blood

oxygen levels using a heart rate monitor, whereas shaking of the arms could be detected via gyroscopes and accelerometers. Both of these technologies are already found in wearable tech products. By measuring and identifying these physiological markers of focus, a context dependent device could be developed that knows when it is time to focus, and it is not. However, this is only useful if the device is also capable of keeping a user focused; in other words, knows when the user loses focus.

Evidence from research suggests that in patients with ADHD, decreased motion is associated with worse executive function. A study involving 29 children with ADHD Hyperactive Impulsive and 23 children without ADHD (8 – 12 years old) compared subjects' activity level to their working memory performance (Sarver et al., 2015). Each subject performed four different working memory exercises while their physical activity levels were monitored and recorded. Results revealed that working memory performance was measurably improved during high rates of physical activity in subjects with ADHD. Conversely, subjects without ADHD had higher working memory performance during lower rates of physical activity. Further research must be (and is currently being) conducted to determine why those ADHD rely on physical motion; but this study provided more evidence for physiological detection of focus. Similar to how they detect exercises, wearable tech could monitor the physical motions associated with working memory functions, and detect when a user's working memory is underperforming.

Another measurable physiological factor associated with ADHD is sleep disruption. Studies suggest that the severity of ADHD symptoms are determined by how well rested a subject is (Gaultney, 2005). For example, one study recorded the sleep patterns of 283 subjects with ADHD (birth – 18+ years old) and compared the sleep

patterns to reported behaviors. The results suggested a strong correlation between poor sleep and an increase in negative behaviors (impulsive acts, resistance to authority, lower cognitive performance). After controlling for age, the correlation was still present. This study suggests that sleep can determine how focused or not focused a subject will be throughout the day. This is information that can be used by a context-aware device. Current wearable tech devices – and smartphones in general – have built in sleep measuring capabilities that detect a user's movement, body position, and noise levels during sleep.

Based on these measurements, a device can determine approximately which stage of sleep a user is in at any given moment. This ability to determine a user's quality of sleep lends itself towards creating a context-aware device. For example, if the device has information that a user with ADHD slept poorly in the previous night, it could be programmed to provide more frequent feedback or monitoring to compensate for poor sleep.

Above all else, however, wearable tech is discrete. Unlike neurofeedback devices such as the MUSE, wearable tech is no less discrete than a wrist watch or pair of glasses. The size and convenience of wearable tech have been the primary drivers of the popularity of wearable tech. This rise in popularity means that as time goes on, everyone – regardless of mental health – will have a wearable device of some form, further decreasing the stigma that might have existed from wearing biofeedback-specific devices.

Conclusion

Using wearable tech, it is possible to create a biofeedback device capable of providing real time feedback therapy for a user with ADHD. This would most likely be achieved through the development of a bespoke algorithm – or app – that measures and responds to the various biological readings provided by the device. Some companies have already begun to develop apps that provide neurofeedback. One such example is FOQUS (Foqus Labs, 2016).

FOQUS is an experimental app that aims to address the mental health issues of ADHD. FOQUS does so by providing a patient with text based alerts, time management techniques, and guided meditation. Initial testing of the app revealed that the app was successful in reducing users' anxiety as well as improving their overall organization skills. However, FOQUS is still not a true biofeedback device. The next step in development would be to develop an algorithm that responds in real time to physical cues. FOQUS is still currently time based, and runs on a predetermined schedule. For example, rather than having a pre-set meditation period, the app would measure heart rate and movement, and if the user's heart rate or movement is beyond normal parameters, the app would prompt the user to take a break or meditate. Similarly, if the app were able to detect overly long periods of stillness, it might prompt the user with a reminder.

In conclusion, the technology to develop a biofeedback device for ADHD is already on the market – and will only continue to improve. However, the efficacy of biofeedback in treating ADHD will only be as great as the applications developed for consumer tech. As wearable tech continues to improve, more and more apps will be released, ushering in a new area of affordable, long lasting, and personalized medicine.

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