Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

Shivam Syal

Middlesex County Academy of Science, Mathematics and Engineering Technologies, Edison, NJ

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

Abstract

Title: Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?
Name: Shivam Syal
School: Middlesex County Academy of Science, Mathematics and Engineering Technologies, Edison, NJ
Teacher: Ms. Katianne, Oakley
Major discipline and sub-discipline: Medicine & Health/Behavioral Sciences - Neuroscience

EPILEPSY, DEPRESSION, PARKINSON'S, ALZHEIMER'S**,** post-traumatic stress disorder (PTSD) - what if the eventual treatment for these brain conditions was not a pill or talk therapy, but some implant? If pacemakers can control the heart, then controlling the brain should be possible. My research from different white papers, initiatives, online resources and talking to experts discovered that Deep-brain stimulation is used to subdue the shakes/tremors of people with Parkinson's disease. Electrodes implanted into a specific part of the brain, connected via wires under the skin to a pacemaker-like stimulator, which sends out electrical signals that stifle the parts of the brain, which cause tremors. Similar devices, or new types of implants, could help people with other complex neurological conditions. A handful of projects devoted to creating the future of brain implants are being funded by the US Brain Research Through Advancing Innovative Neurotechnologies (BRAIN) Initiative, an effort to accelerate humankind's understanding of the brain. Restoring Active Memory (RAM), aims to use implants to improve soldier's memories after traumatic brain injury. Systems Based Neurotechnology for Emerging Therapies (SUBNETS), develops devices to treat PTSD, chronic pain and anxiety. This research paper elaborates on the implementation, effects and future work of brain implants.

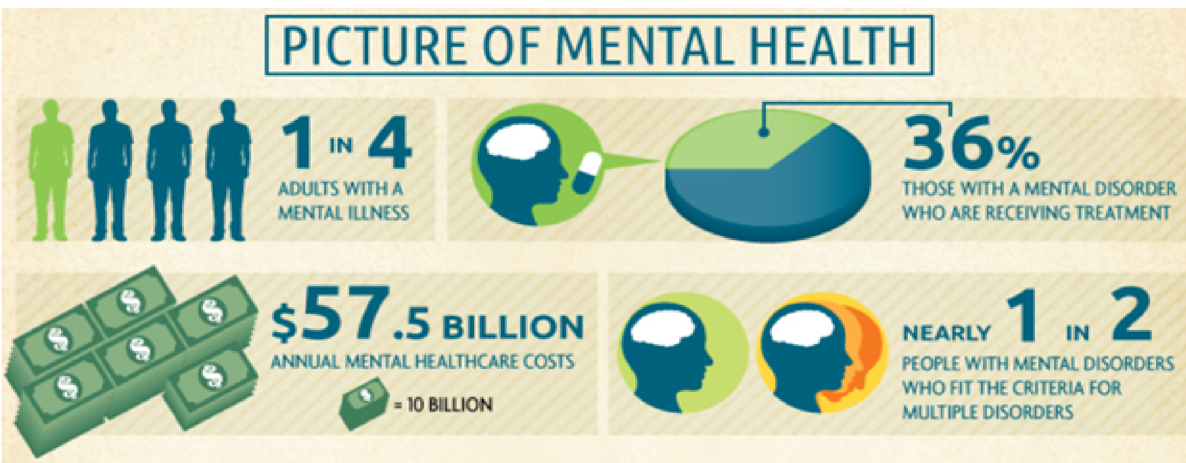
Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

Table of Contents

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

Introduction

As per the National Institute of Health, a mental illness can be defined as a health condition that changes a person's thinking, feelings, or behavior (or all three) and that causes the person distress and difficulty in functioning. [10] The term mental disorder is also used to refer to these health problems. From Alzheimer's disease to depression, an estimated one in four people worldwide will face a neurological or psychiatric condition, causing enormous financial and social burdens. [8] Healthcare is costing $57.5 billion on those with a mental disorder who are receiving treatment via pills or therapy. Below, the infographic shows statistics of Mental Health. [9]



Neuro-technology can provide benefit over traditional methods when treating mental illness using pill or talk therapy, and can translate into less frequent patient visits to doctors with potential of significant healthcare cost savings and happy patients. The following exploratory research paper will discuss the kind of mental illnesses/disorders that occur due to the imbalance of chemicals in the brain, limitations of current pill treatments, availability of successfully used

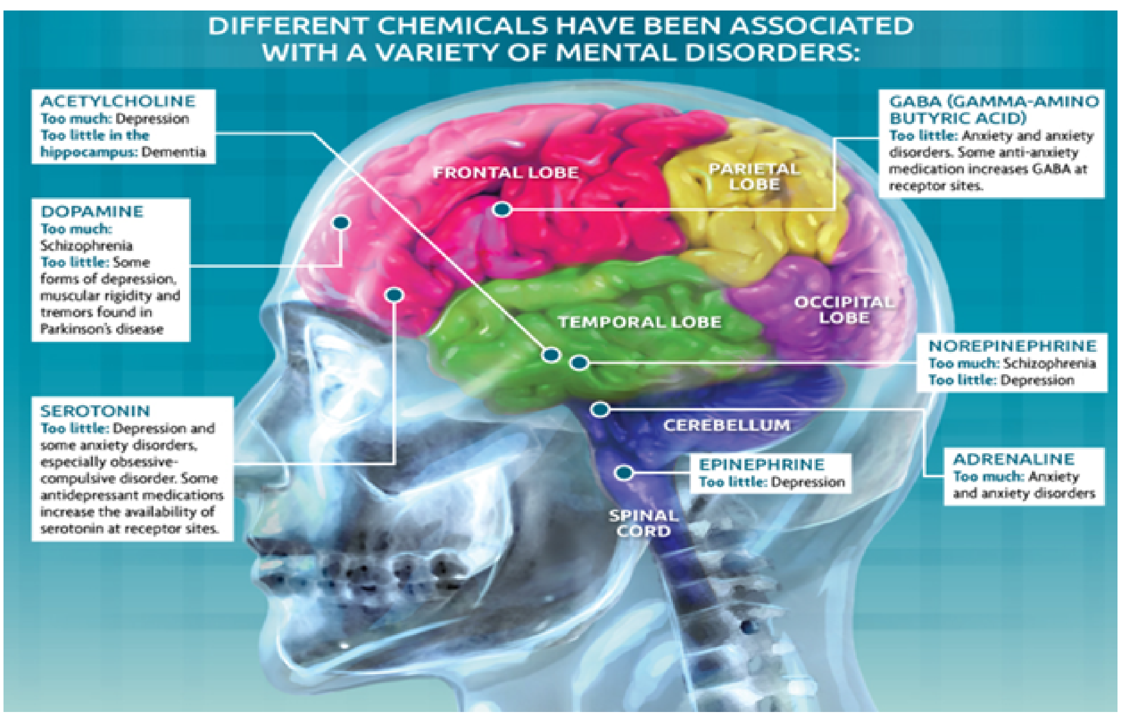
Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

neuro-technologies, carriers to implementing each technology, as well as some strategies for overcoming these barriers.

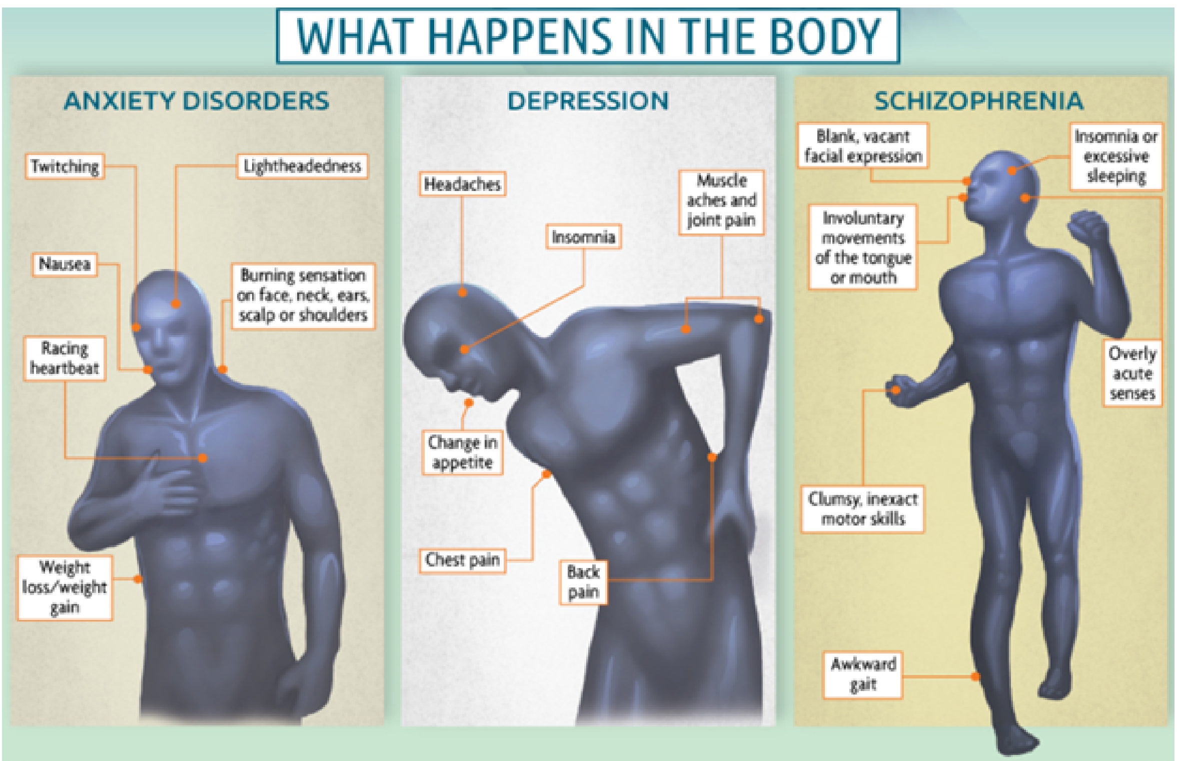
Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

Materials and Methods

Scientists who study mental illness believe an imbalance in brain chemicals (a.k.a. neurotransmitters) which are generated due to electric signals in brain contributes to the development of many mental disorders. Researchers suspect this imbalance impedes the brain's ability to move messages from neuron to neuron and for the brain's wiring to function normally. Because of this breakdown, the brain may not communicate properly with the body, and a person may begin to show signs of mental illness. The brain is primarily divided into four regions (a.k.a. lobes), along with the cerebellum, and each region is responsible for specific function of the body from sensing an input to controlling the response, which could be movement of a body part, emotion or memory. Below is quick reference to Brain Map [9] with regions and brain chemicals imbalance of which is associated with one or other mental disorders.



Neuro-technology: Can new technologies be used to treat mental illness or enhance memory? As shown in below diagram [9], typical symptoms of a specific disorder vary. Some other disorders like Alzheimer, Parkinson, Epilepsy, etc have different symptoms (not discussed in this representation). As per traditional treatment, doctors identify symptoms, conduct an Electroencephalogram (EEG) or Magnetic resonance imaging (MRI) to further confirm their initial diagnosis and generally prescribe therapy or specific pill to rectify the imbalance of chemical responsible for specific disorder.



However, traditional treatment options, including psychotherapy and medication, are no guarantee of relief from symptoms that hinder the normal activities of everyday life for the person with mental illness. Neuroscience suggests that mental disorders which arise from abnormal brain circuits, and that traditional therapies may not target these underlying neural dysfunctions.

Deep Brain Stimulation (DBS), where precisely directed pulses of electrical current stimulate dysfunctional brain circuits to alter neural activity, is emerging as a viable alternative some patients who feel no relief from medication and psychotherapy. [5]

In early tests at Draper Laboratory, DBS showed promise for treating treatment-resistant depression and obsessive compulsive disorder (OCD). [5] In clinical trials, however, those results could not be replicated. The poor outcomes could be explained by the open-loop nature of the implanted device, which means that stimulation was delivered not based on measured input, and without regard to when, and the degree to which, brain activity becomes dysfunctional. Because mental disorders are dynamic, meaning symptoms and neural dysfunction wax and wane over time, new research suggests that it is important to control stimulation based on when neural activity becomes dysfunctional.

“Harnessing the full potential of DBS for the treatment of mental illness requires an adaptive, closed loop approach backed by quantitative measures of neural activity that signals when to turn stimulation on and off,” said Nicole Provenza, a Brown University graduate student, Draper Fellow and a member of a research team at Draper that is studying DBS. [5]

Closed loop control system is also commonly known as Brain Implant. In this method, a chip is implanted to your brain, which closely monitors brain activity, turns the simulations of specific brain chemical responsible for a disorder, learns the pattern and adjusts according to brain

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

activity. It not only can correct disorder but also can be used for enhancing other brain functions like memory.

Results

This section discusses some successful Brain Implants to correct mental disorders or enhance memory.

Responsive Neurostimulation (RNS) to treat Epilepsy [3]

At least 30% of people do not respond to seizure medicines. Some people can have surgery to remove where seizures start in the brain. This treatment is the only way to cure epilepsy, but it doesn’t work in everyone. On average, only about 60% of people can be free of disabling seizures from removal of a seizure focus in the temporal lobe. VNS Therapy or dietary therapies, such as the ketogenic diet, may help many people. Another option is responsive neurostimulation. Known as RNS® Therapy, this new seizure treatment was approved by the U.S. Food and Drug Administration (FDA) in 2013.

Everyone’s seizures are a bit different, either in type, number, or pattern. Therefore an ideal way to treat seizures is personalizing the treatment to each person. The ability to give the treatment only when it’s needed (at the time of a seizure or suspected seizure activity in the brain) is a key feature of the RNS® System.

The RNS® System is designed to work in 3 key ways:

- **Monitor** brain waves at the seizure focus, all the time - even during sleep.
- **Detect** unusual electrical activity that can lead to a seizure.
- **Respond** quickly (within milliseconds) to seizure activity by giving small bursts or pulses of stimulation. This goal is to help brain waves return to normal, even before it could turn into a seizure.

Seizure Reduction Results

- 230 patients with the RNS® System were followed over time in a controlled trial. The average decrease in seizures was 44% after 1 year, 53% at 2 years, and up to 66% after 3 to 6 years of using RNS.
- The same trend was seen when some of these people were followed for 7 years. Seizures decreased by an average of 72%.
- So far, 2 out of 3 people with the RNS® System (66%) had their seizures cut in half after 7 years of using it.
- Some people had extended times of being seizure free as well. In the open label study or long-term study, 1 out of 3 people reported periods of no seizures for 6 months in a row.

Deep Brain Stimulation to treat Alzheimer's [1, 2]

According to a 2016 study by that was published in Alzheimer's and Dementia by National Institute of Health, in the United States, someone develops Alzheimer's disease every 66 seconds. By 2050, one new case of Alzheimer's is expected to develop every 33 seconds, resulting in nearly 1 million new cases per year.

There is currently no cure for Alzheimer's disease, so treatments focus on managing its symptoms. It is particularly important for people living with this condition to be able to carry out their day-to-day activities for as long as possible, in order to maintain a good quality of life.

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory? A recent clinical trial conducted by specialists at the Ohio State University Wexner Medical Center in Columbus tested the efficiency of implants for deep brain stimulation in helping people with Alzheimer's to keep living independently for longer.

Dr. Douglas Scharre and colleagues' method requires implanting very thin electrical wires into the brain's frontal lobes, which are associated with working memory and executive functioning, which makes that area of the brain crucial in decision-making.

Self-tuning brain implant to treat patients with Parkinson’s [7]

Deep brain stimulation has been used to treat Parkinson’s disease symptoms for 25 years, but limitations have led researchers to look for ways to improve the technique. The study supported by the National Institutes of Health’s Brain Research through Advancing Innovative Technologies (BRAIN) Initiative and the National Institute of Neurological Disorders and Stroke (NINDS) describes the first fully implanted DBS system that uses feedback from the brain itself to fine-tune its signaling.

“The novel approach taken in this small-scale feasibility study may be an important first step in developing a more refined or personalized way for doctors to reduce the problems patients with Parkinson’s disease face every day,” said Nick B. Langhals, Ph.D., program director at NINDS and team lead for the BRAIN Initiative.

Deep brain stimulation is a method of managing Parkinson’s disease symptoms by surgically implanting an electrode, a thin wire, into the brain. Traditional deep brain stimulation delivers constant stimulation to a part of the brain called the basal ganglia to help treat the symptoms of

Parkinson's. However, this approach can lead to unwanted side effects, requiring reprogramming by a trained clinician. The new method described in this study is adaptive, so that the stimulation delivered is responsive in real time to signals received from the patient's brain.

"This is the first time a fully implanted device has been used for closed-loop, adaptive deep brain stimulation in human Parkinson's disease patients," said Philip Starr, M.D., Ph.D., professor of neurological surgery, University of California, San Francisco, and senior author of the study, which was published in the Journal of Neural Engineering.

In a short-term feasibility trial, two patients with Parkinson's received a fully implanted, adaptive deep brain stimulation device. The device differs from traditional ones in that it can both monitor and modulate brain activity. In this work, sensing was done from an electrode implanted over the primary motor cortex, a part of the brain critical for normal movement. Signals from this electrode are then fed into a computer program embedded in the device, which determines whether to stimulate the brain. For this study the researchers taught the program to recognize a pattern of brain activity associated with dyskinesia, or uncontrolled movements that are a side effect of deep brain stimulation in Parkinson's disease, as a guide to tailor stimulation. Stimulation was reduced when it identified dyskinesia-related brain activity and increased when brain sensing indicated no dyskinesia to minimize deep brain stimulation-related side effects.

Results of initial, short-term studies aimed at demonstrating feasibility and effectiveness of using adaptive deep brain stimulation to overcome the impediment to movement of

Parkinson's suggested that this adaptive approach was equally effective at controlling symptoms as traditional deep brain stimulation. Doctors saw and patients noticed no differences in the improvement in movement under adaptive stimulation versus constant, open loop stimulation set manually by the researchers. Because adaptive deep brain stimulation did not continuously stimulate the brain, the system saved about 40 percent of the device's battery energy used during traditional stimulation. The short time periods over which movement was assessed did not permit comparison of the two deep brain stimulation paradigms relative to incidence of dyskinesia, but it is hoped that the variable stimulation will also translate into a reduction in adverse effects when tested over longer time periods.

"Other adaptive deep brain stimulation designs record brain activity from an area adjacent to where the stimulation occurs, in the basal ganglia, which is susceptible to interference from stimulation current" said Dr. Starr. "Instead, our device receives feedback from the motor cortex, far from the stimulation source, providing a more reliable signal."

Closed-loop stimulation of temporal cortex rescues functional networks and improves memory [4]

The research team, led by scientists at the University of Pennsylvania and Thomas Jefferson University, last year reported that timed electrical pulses from implanted electrodes could reliably aid recall.

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

Memory failures are frustrating and often the result of ineffective encoding. One approach to improving memory outcomes is through direct modulation of brain activity with electrical stimulation. Previous efforts, however, have reported inconsistent effects when using open-loop stimulation and often target the hippocampus and medial temporal lobes. Closed-loop system was used to monitor and decode neural activity from direct brain recordings in humans by applying targeted stimulation to lateral temporal cortex, which rescues periods of poor memory encoding. This system also improved later recall, revealing that the lateral temporal cortex is a reliable target for memory enhancement.

In the study, the research team determined the precise patterns for each person's high-functioning state, when memory storage worked well in the brain, and low-functioning mode, when it did not. The scientists then asked the patients to memorize lists of words and later, after a distraction, to recall as many as they could.

Twenty-five patients undergoing intracranial electroencephalographic monitoring as part of clinical treatment for drug-resistant epilepsy were recruited to participate in this study. Data were collected as part of a multi-center project designed to assess the effects of electrical stimulation on memory-related brain function. Each participant carried out a variety of tests repeatedly, recalling different words during each test. Some lists were memorized with the brain stimulation system turned on; others were done with it turned off, for comparison. On average, people did about 15 percent better when the implant was switched on

Discussion and Conclusion

In this research, I show that traditional treatment options, which do not guarantee of relief from symptoms, are not the only way to treat mental disorders. With some already successfully implemented closed loop brain implants (such as RNS for Epilepsy) and others, where clinical trials have shown success (like for Alzheimer's, Parkinson's and memory enhancement), the future for mental disorders treatment has proven to be neurotechnology. But these devices face many hurdles en route to the clinic. What materials will work best with brain tissue? Can implants become target for attacks and control the humans? Can implants be made wireless and small enough to fit into a skull? Can a single implant can treat multiple disorders by stimulating different areas of brain?

Professors at University of Berkeley, California have developed Neural Dust, an ultrasonic backscattering system to record information from the human body. This was motivated by one of the main problems in brain-machine interfaces: how to make a technology that will last in the brain for decades, if not a lifetime, and that is also wireless. Neural Dust uses ultrasound waves to power tiny, wireless sensors that can be implanted in the body and read its output. Brain activity sensors called "neural dust" UC Berkeley bioengineers Jose Carmena and Michel Maharbiz invented tiny sensors they call “neural dust” to wirelessly monitor, and even stimulate, the brain and other organs. Think of it like a Fitbit, but internal. [6]

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory? Some of the initiatives run by DARPA with One, Restoring Active Memory (RAM), aims to use implants to improve soldier's memories after traumatic brain injury. Another, called the Systems Based Neurotechnology for Emerging Therapies (SUBNETS) program, is developing devices to treat PTSD, chronic pain and anxiety.

The current findings demonstrate that closed-loop stimulation approach in patients with brain implants could be useful.

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

References

1) Alzheimer's, A s. “2016 Alzheimer's Disease Facts and Figures.” *Current Neurology and Neuroscience Reports.*, U.S. National Library of Medicine, Apr. 2016, Accessed on September 4, 2018 www.ncbi.nlm.nih.gov/pubmed/27570871.

2) Cohut, Maria. “Alzheimer's: Brain Implant Could Improve Cognitive Function.” *Medical News Today*, MediLexicon International, 31 Jan. 2018, Accessed on November 4, 2018 www.medicalnewstoday.com/articles/320792.php.

3) Iyengar, Sloka, and Patricia O. Shafer. “Responsive Neurostimulation (RNS).” Edited by Mohamad Koubeissi and Joseph I. Sirven, Epilepsy Foundation, Nov. 2017, www.epilepsy.com/learn/treating-seizures-and-epilepsy/devices/responsive-neurostimulation-rns. Accessed on August 20, 2018.

4) Ezzyat, Youssef, et al. “Closed-Loop Stimulation of Temporal Cortex Rescues Functional Networks and Improves Memory.” Nature News, Nature Publishing Group, 6 Feb. 2018, www.nature.com/articles/s41467-017-02753-0. Accessed on December 9, 2018

5) “Mapping the Brain to Address Mental Illness.” Draper, Draper Laboratory, 24 May 2017, www.draper.com/news-releases/mapping-brain-address-mental-illness. Accessed on November 24, 2018.

6) “Scientists Want to Use Brain Implants to Tune the Mind.” *The Brain or the Universe – Where Does Math Come From? | The Kavli Foundation*, www.kavlifoundation.org/science-spotlights/scientists-want-use-brain-implants-tune-mind#. Accessed on October 21, 2018.

Neuro-technology: Can new technologies be used to treat mental illness or enhance memory?

7) “Self-Tuning Brain Implant Could Help Treat Patients with Parkinson's Disease.” *National Institutes of Health*, U.S. Department of Health and Human Services, 29 May 2018, Accessed on September 4, 2018 www.nih.gov/news-events/news-releases/self-tuning-brain-implant-could-help-treat-patients-parkinsons-disease.

8) Society for Neuroscience. “Brain Facts: A Primer on the Brain and Nervous System.” 2018. PDF File.

9) The Editors at Best Masters in Psychology. “The Science of Mental Illness.” Best Masters in Psychology, www.bestmastersinpsychology.com/science-mental-health/. Accessed on November 05, 2018.

10) US, National Institutes of Health. “Information about Mental Illness and the Brain.” Current Neurology and Neuroscience Reports., U.S. National Library of Medicine, 1 Jan. 1970, www.ncbi.nlm.nih.gov/books/NBK20369/. Accessed on November 08, 2018.