Changing Your Mind: Creating Tangibility in Neural circuits in Order to Increase Neurotechnological Efficacy

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ABSTRACT

Neuroscience is an ever-evolving field that grows each day. It has branched into many different fields of study but a novel area of research is neurological technology (Neurotechnology). Neurotechnology has enabled for victims of various neurological disorders to manage their symptoms and lead normal lifestyles. But how can one improve neurotechnology? Like any device there is always a better model, a more efficient one. The body doesn't need help healing itself but neurotechnology can help. Another question one could ask is how does the body's ability to heal itself help neurotechnology? Given the dynamic nature of neurotechnology, anything that can support it will work to boost the technology's advantages. Therefore, integrating the old and modern can only lead to great results, and the little drawbacks and side effects may be overlooked due to the collaboration's immense value. In conclusion, neuroplasticity is a factor that may have an impact on how effective neurotechnologies are. It should be taken into account while creating new kinds of instruments, and treatment strategies should take the variability this association brings into account.

Context

Neurotechnology is the perfect combination of engineering and biology. This type of science is the integration of the computer, mechanics, and neurological studies. Managing neurotechnology "intelligently and benevolently is going to be one of the most essential things the human race will ever undertake" [1] . Neurotechnology is not only medical devices but is an evolving field of consumer products as well. This includes various interfacing that allow one to interact with technology around themselves. It may sound like science fiction but neurotechnology has the potential to have a kind of thinking decoding capability. However, brain-computer interfaces (BCIs) are novel inventions which have a high range of variability. Another aspect, DBS (Deep brain stimulation) technology, is definitely a more researched method. Deep brain stimulation is the electrical stimulation of the neural systems in order to aid neural connectivity and aid in the healing of neural pathways. DBS technology can be used to manage symptoms of various disorders including those pertaining to mood, memory, sleep, and motor skill [2, 3]. Given this information, neurotechnology is a field that is still underdeveloped and needing more funding and research[3].

On the other hand, neuroplasticity is a more researched field. Neuroplasticity is the study of the brain's ability to change and rewire itself. It focuses on the biological ability to make new synaptic connections and the ability for self-regeneration. In fact, a recent study tracks "the development of synaptic connections' ' from previously inhibited or damaged pathways over time[4]. New cells can develop in the adult brain, and healthy neurons can add new nerve endings to connect with other cells. It is now understood that the brain builds new connections as it reorganizes itself over the course of a lifetime. This mechanism gives the brain the ability to make up for lost function as a result of sickness or damage and to rearrange its activity in response to novel experiences or environmental changes [5]. Overall, neuroplasticity aids in the growth and recovery of brain function. But how can it be applied to further benefit human health and palliative care of neurological disorders?

Stroke

When the blood flow to a portion of the brain is interrupted or diminished, brain tissue cannot receive oxygen, resulting in an ischemic stroke. Stroke can cause paralysis, loss of motor function, vision impairment, and other disabilities. In an April 2022 study at Tongji University in Shanghai, the results show that BCI-based rehab could be a successful intervention for patients who have mild to severe upper limb paresis after stroke, and it constitutes a possible stroke neurorehabilitation strategy[6]. In order to investigate the potential positive effects of physiotherapy alone in chronic stroke moderate - to - severe paresis, they assessed the effectiveness of brain-computer interface (BCI) training. They also concentrated on how BCI training affected the primary motor cortex (motor cortex neuroplasticity) in 18 hospitalized chronic stroke patients with moderate or severe motor deficits[6].

Furthermore, a October 2022 study done in Taipei Medical University and University of Sydney Australia examined how the flexibility of motor axons caused by changes to the corticospinal tract (major neuronal pathway providing voluntary motor function) during the poststroke stage is reflected in ischemic stroke patients with hemiparesis or hemiplegia (paralysis caused by stroke)[7]. The study of motor axon flexibility is directly related to the neuroplasticity of the nervous system and neurons. It was found that lower motor neurons' neuronal excitability (which enables movement) can vary as a result of upper motor neuron impairment following a stroke, and the changes are more pronounced in severely paralyzed limbs. After a stroke, the accommodating alterations of the axons move from the subacute to the chronic stage. To better understand how an upper motor neuron injury affects the peripheral nervous system, more research is required [7]. The neuroplasticity of the brain is just as variable as neurotechnology because the plasticity of one neuron may be responsible for an unintended function as seen above.

Accomplished science journalist Sharon Begley wrote in the science column *Wall Street Journal* that neuroscientists claim that other stroke-related impairments can learn from the apparent success of using neuroplasticity to recover vision. "Targeted therapies that take advantage of neuroplasticity are always a possibility. Additionally, it is not age-dependent because the brain can radically restructure itself at any age"[8]. These neuroscientists have developed methods to educate healthy neurons to carry out the task of those destroyed or damaged by the stroke, taking advantage of an advancement in brain science. There are 700,000 stroke patients in the United States each year, and about 10% to 15% of them lose some or all of their vision. Long ago, medical professionals and rehabilitation experts believed that stroke-related partial blindness was incurable and had a worse prognosis than the partial paralysis it can sometimes induce. Now, with the help of neuroplasticity and even neurotechnology stroke victims have potential recovery of motor and sensory function[8].

Mental Health

Stroke is merely one neurological disease so what of more psychoneurological disorders? Although depression is one of the most prevalent mental illnesses in contemporary culture, little is known about its pathogenesis. An October 2021 study by Ioana Radulescu, Ana Miruna Dragoi, Simona Corina Trifu and Mihai Bogdan Cristea done at the University of Bucharest evaluates a substantial body of research demonstrates that depression alters the neuroplasticity of particular brain regions in ways that are connected to the severity of the symptoms, negative emotional rumination, and the learning of fears. Neuronal shrinkage in the limbic and cortical brain areas that regulate mood and emotion is linked to depression[9]. Contrary to popular conception, neuroplasticity isn’t always beneficial though. Depression can bring a type of neuroplasticity that is detrimental to brain and neural health. However, antidepressant medication has the ability to counteract the detrimental neuroplasticity brought on by depression [9, 8]. This brings up the question, what can be done so neuroplasticity can be mediated so it is only beneficial to the human body?

Historically, medication has always been seen as the path for dealing with psychoneurological disorders. A Wayne State University School of Medicine report analyzes a reconceptualization of the pathogenesis, course, and ideal long-term therapy of recurring mood disorders is necessary, according to evidence from a variety of clinical and preclinical, experimental, and naturalistic settings. Regardless of the primary, symptomatic treatment, it was viewed that the best long-term outcomes for many serious disorders can only be obtained by using drugs with neurotrophic/neuroprotective properties as soon as possible. Such therapeutic approaches would improve neuroplasticity and cellular resilience by impacting key molecules involved in pathways for cell survival and death[10]. Overall, the focus of “curing” psycho- neurological disorders needs to evolve from being purely pharmacological.

Sleep and its Importance

When parents tell their children that sleep is important, they really mean it. Sleep is crucial for cognition, especially for the development of learning and memory, as it has a significant impact on synapse strength. It is unclear whether and how sleep deprivation affects the physiology and cognition of the human brain[11]. According to studies, sleep deprivation increases brain excitability and changes plasticity, which are linked to poor cognitive function. The findings have implications for variability and the best use of noninvasive brain stimulation in addition to demonstrating how changes in brain physiology and cognition (from neurophysiology to higher-order cognition) occur under sleep pressure[11]. The study demonstrates that sleep deprivation impairs working memory and attention, both of which depend on cortical excitability and learning and memory formation, behavioral counterparts of plasticity[11].

In a review done by Italian researchers Laura Palagini and Carlotta Bianchini, pharmacological treatments have proven to help aid in sleep related (more specifically insomniatic) inhibition of plasticity. Insomnia is a stress-related sleep condition that can favor an allostatic overload state that impairs brain neuroplasticity, stress immunological and endocrine pathways, and may be a factor in both physical and mental illnesses. Assessing and treating insomnia are crucial in this framework. They may need to reevaluate how they employ hypnotic substances in clinical practice in light of current models of insomnia. Compounds should specifically target the stress system, sleep processes, and maintain brain plasticity. In this context, triazolam, a short/medium acting hypnotic benzodiazepine, has received the greatest research attention, while eszopiclone, a Z-drug, has shown intriguing results. Both provide potentially novel treatment options for insomnia[12]. But once again the sole reliance on pharmaceuticals might be a bit old-fashioned. As the world moves toward neurotechnological solutions, shouldn’t the medical field too?

Advances in the Field

Starting in the early 2000s there has been an increased show of support for neuroscientific research. A press release from the Neurotechnology Industry Organization on May 7, 2008 states that the National Neurotechnology Initiative Act, introduced by a bipartisan group of distinguished members of both houses of Congress, aims to promote research and hasten the development of new and safer treatments for brain-related illness, injury, or disease[13]. This act is still in use today but funding has turned to different aspects of neuroscience, even fields such as brain mapping (which is very closely related to neuroplasticity).

Another advancement in the field of neuroscience, more specific to neurotechnology, is Neuralink. The purpose of neuralink is to create a BCI that can wire your brain to a device or allow you to communicate with technology that surrounds you. The results are not yet known. Neuralink is an idea formulated by tech billionaire Elon Musk. Elon Musk, as of now, expects Neuralink to be able to general consumer population sometime in the next 10 years. The results are likely to be determined after clinical trials. This product is not FDA approved but the research team is growing and innovating[14].

In other innovation, deep brain stimulation (DBS) has been shown experimentally to cause short-term synaptic plasticity (STP) in the stimulated nucleus in both human and animal investigations. A group of researchers at the University of Toronto set out to create a computational predictive model that can anticipate the dynamics of STP in response to DBS at various frequencies since it is possible that DBS-induced STP is related to the therapeutic effects of DBS. Both model-based and model-free approaches to predicting STP currently in use need access to pre-synaptic spiking activity. However, extracellular stimulation (like DBS) can be used in the setting of DBS to directly induce presynaptic activations. Extracellular means that the stimulation is located or occurring outside of a cell or cells. An important characteristic of neural networks that is involved in brain information processing is short-term synaptic plasticity (STP). STP makes it possible for neurons to interact with one another across a range of frequency bands (measurement of brain waves). Based on previous presynaptic activity, this feature can change a synapse's strength and controls the frequency band at which information is sent [15].

Gap Identification

There has been research on the fields of neuroplasticity and neurotechnology separately. But what happens when one thinks to combine them? Will the efficacy of neurological technology change when the principles of neuroplasticity are applied upon it? Neuroplasticity has the potential of function recovery on its own, but neurotech could help it do more than it ever could alone. The gap in the research is the collaboration of these two fields in order to help people with various neurological disorders, specifically stroke and psychoneurological disorders. How can neuroplasticity aid in the efficacy of neurotechnological solutions for various neurological disorders?

Methods

In order to evaluate this situation I utilized the method of correlational research. Correlational research is defined as the inspection of two factors to test correlational effects or relationships. Correlational research fulfills the needs of this inquiry because it allows me to study the relationship between two topics. This type of research can be theoretical qualitative or analytical quantitative. I choose a more theoretical qualitative approach. The two factors that I wanted to find correlation for were increase in neuroplasticity (*Y*) and the efficacy of neurotechnology (*X*). The goal of the research was to evaluate if a change in *Y* resulted in a change in *X*. If so, what exactly are the causes that lead to this correlation; if not, why are *X* and *Y* not correlated to each other. To create my study, I gathered data from various studies from the *Frontier Journal of Neuroscience* and other academic databases. These studies provided me with clinical trial data to create my correlation analysis graph. From these studies I determined elements could work towards the increasing of neuroplasticity. The elements were decided upon based on the May 2018 study, "*Nicotinic Restoration of Excitatory Neuroplasticity…*", by Jessica Grundey and the November 2018 study, "*Enhanced Plasticity of Human Evoked Potentials by Visual Noise…*", by Jun Xie. The first step of the process was to find the elements that increased neuroplasticity, which I determined as random noise stimulation and nicotine (psycoactivators). Then, I evaluated if the resulting effects of the elements that increased neuroplasticity related to a change in the efficacy of neurological technology. Furthermore, the efficacy of neurotechnology is measured in how fast the end result programming (the action that the device is programmed to carry out) can occur. The increase of neuroplasticity is found to control neural pathways and activity. Does the change in this activity result in the better function of neurological devices?

Neurotechnology requires excellent connection of several neural pathways in order to carry out its purpose. Additionally, to evaluate the connection one would need to measure synaptic transmission rate between the technology and the nervous system. To connect the two factors, one would consider if the increase in neuroplasticity results in a faster synaptic transmission rate?

Overall, these questions guided the goal of the study. I explored the relationship between the two factors that are involved in many neurological disorders. The correlation between X and Y was the final outcome of my research. To depict the correlation, I created a line graph that accounted for the variability of neural technologies and neuroplasticity. I furthered my research by also identifying the point where the correlation between the factors became obsolete.

Results and Findings

In my research I found that the increase of neuroplasticity resulted in more tangible and flexible neural pathways. Random noise stimulation may enhance the impact of behavioral training with discernible brain changes by modifying the excitability of neural networks, which may ultimately result in neuroplasticity [16]. The random noise consisted of visual and auditory stimulation. These effects were measured with the use of an EEG and revealed that the noise-tagged intervention enhanced the potentiation effect more effectively over continuous use than the traditional non-noise paradigm (as seen in Figure 3). The amplitudes of reaction were decreased without the sound revealing that stimulation with noise results in faster neural connection.

Another type of element that creates tangibility in the neural pathways is nicotine[17]. The primary psychotropic substance in tobacco, nicotine is also what gives it its addictive qualities. Research on both animals and people have demonstrated that nicotine administration can enhance memory performance, concentration, and episodic memory [18]. The study done with nicotine, as a neuroplasticity inducer, has shown outcomes of faster reaction times and pronounced action potential as seen in Figure 1; the side effects of cigarettes are avoided by utilizing a spray medium of nicotine. The spray was also supplemented with MEP, a potential energy activator. The MEP helped create more potential energy in the neural circuits. The test group was made up of 31 healthy adults ranging from the ages 23 to 31. In addition, the gender varied such as this:14 females and 17 males. This means that the synaptic transmission rate of information occurred at a faster pace. Synaptic mechanisms that promote or restrict changes in neuronal circuits are closely regulated by neuroplasticity [19]. The combination of techniques and tools that permit a direct link between technological elements and the neurological system is known as neurotechnology. Electrodes, computers, or intelligent prosthetics are examples of these technical components. They are intended to either "translate" brain signals into technical control orders by recording them, or to alter brain activity by delivering electrical or visual stimulation [20]. Since the brain signals are being interpreted faster by the synaptic mechanisms due to increased neuroplasticity, neurotechnological hardware has a greater capacity to interpret and carry out programming.

There is a positive correlation between the increase of neuroplasticity and the increase in efficacy of neurotechnological devices. The factors *X* and *Y* do relate in a positive context. The relationship between the two could be viewed as a linear relationship however the graph would eventually exponentialize. The exponentialization is cut off for efficacy in neurotechnology. Figure 2 demonstrates this concept. The capacity of current hardware has a limit for connectivity and the safety of that hardware integrated into the human body needs to be considered [20]. Hardware can only facilitate a certain number of bites, digital information, so that means that after a certain point the received information will not be effectively translated.

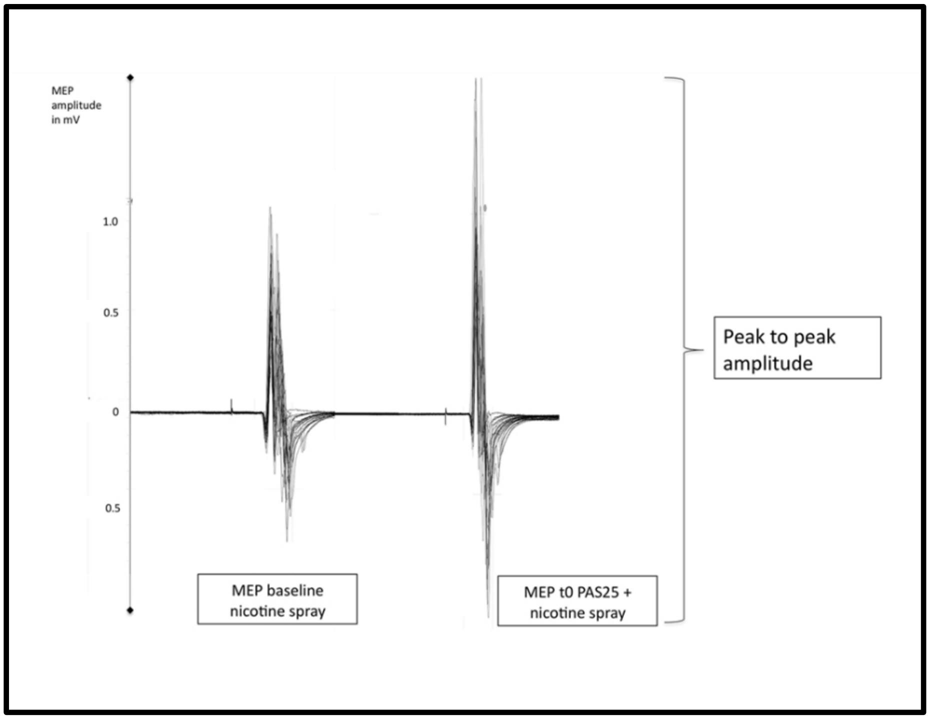

Figure 1 (Grundey J, Thirugnasambandam N, Amu R, Paulus W, Nitsche MA)

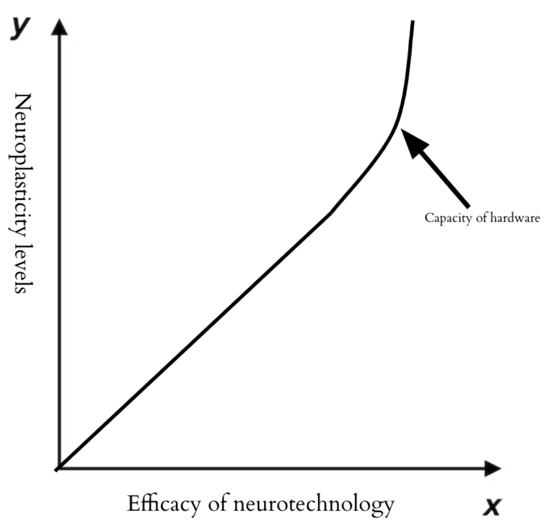

Figure 2- The arrow points to the point at which the efficacy of neurotechnology plateaus as a result of hardware capacity.

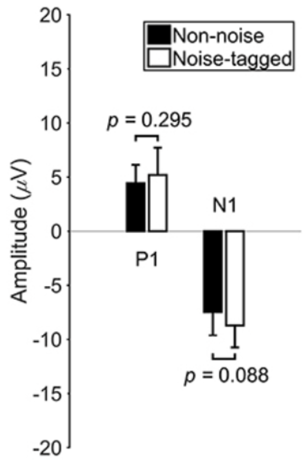

Figure 3- (Xie J, Xu G, Zhao X, et al.)

Discussion and Analysis

By stimulating neuroplasticity through external factors such as the administration of a psychotropic substance such as nicotine or random noise, we could increase efficacy in neural technologies. When the psychotropic substances were applied the amplitude of the neural circuit waves increased. Increased amplitude means increased connectivity. Furthermore, increased connectivity relates to faster speed of circuits. Which is interpreted for the parameters of my study as a higher efficacy of neurotechnology. Stimulation with the use of addictive substances, such as nicotine, could prove a detrimental factor in development concerning neuroplasticity and neural technologies. One can determine that if neurotechnology needs connectivity in order to function, increasing connectivity ensures the increase of efficacy. Therefore, more neuroplastic capability translates directly to more effective neural technologies. The increase in the synaptic communication rates can be directly correlated to faster technological translation (meaning the end action programming is happening at a faster rate). And for the purpose of this study speed is a determinant for efficacy in neural technologies. From the analysis of the two factors in relation to each other, we can conclude that the neuroplasticity in some capacity does equate to more effective neurotechnological devices. For example, with relation specifically to Deep Brain Stimulation (DBS), the faster communication for an activation of electrical stimulation allows the DBS device to send out the electrical impulses faster. This could result in better palliative care for neurological disorders that can be remedied by neurotechnology. In stroke recovery and dementia related diseases (Alzhiemers and Parkinson's), DBS technology has shown to improve and preserve anatomical conditions [21]. By preserving the conditions of disease progression, we are able to better treat a variety of neurological diseases.

So by improving this technology we are improving the care we provide for patients with these conditions. The technology itself will be more effective in carrying out its intended processes. With this realization, researchers can now explore other factors that affect the efficacy of neural technology. This could range anywhere from the type of hardware used for the technology to the stage of development of the disease the technology is trying to remedy. Furthermore, this correlation will allow for more acuity in treatments involving neural technologies supplemented with other pharmacological/behavioral treatment.

Conclusions and Future Directions

Neurological technology is the next frontier after medicine. Not only is it beneficial for neurological disorders, eventually the development will allow for the devices to remedy diseases that plague all parts of the human body. My research has helped me understand that the brian can be better calibrated to integrate with the neurotechnological devices. This calibration allows for better reception and projection of neural commands. By increasing the acuity of technology, science is moving a step forward in the right direction.

This field is very new making it difficult to access resources and get approval for research. Government policy on this type of research is still very limiting and the lack of human subjects (overall) has limited us from fully understanding the technologies in development. Technology itself is an expensive endeavor and lacks funding; issues of ethics will surely arise as well. The ethicality issues will amass in difficulty expanding on the technology. This considered, the benefits of developing this area of science far outweigh the potential risks and side effects. Eventually, neurological technology like phones and computers will become a marketable consumer product. So, while it is in development, it is important for researchers to create the most effective and safe device possible. My research will help create a consumer product that is effective in its goal. Like many consumer products, neurotechnology will become widely marketed and we must ensure that marketing is done in a responsible manner.

Yet, there will be issues on how to make sure that the products produced are accessible to the general public and not just specific groups. Government policies will need to be put in place to ensure that the development is monitored and overseen every step of the way. Ultimately, neuroplasticity is just one of many factors that can influence the effectiveness of neural technologies in a medical setting. But the positive correlation between the two factors will lead to further research and development to improve the acuity of all neurotechnologies (commercial and medical). Diseases will be better treated and the technology will become more reliable; this will result in better palliative care for patients with all kinds of ailments.

Post-stroke and psychoneurological disorders can be more effectively treated due to this revelation. This will be done through the implementation of neuroplasticity stimulators into the treatment plans of these categories of patients. With this supplementation, neurotechnological instruments can provide palliative care. For example, in post stroke patients, increasing neuroplasticity translates to faster neurotechnological connection. This means that the post stroke deep brain stimulation will more accurately administered. In addition, psychological disorders treated with deep brain stimulation will also benefit in the same manner as stroke patients. Of course this should not be the only medium of therapy or treatment. These disorders should be supplemented with occupational therapy, pharmaceutical approaches, and even surgical repairs (if applicable). Implementing treatment based on the correlation of neuroplasticity and neural technologies works towards more effective treatment. This does not mean that this treatment is a cure. Rather, it creates the position in which this treatment is palliative therapy.

In future studies, researchers should examine when neuroplasticity plateaus without the plateaus of neurotechnological efficacy due to hardware capacity. Furthermore, researchers could also study other factors that could be influenced by technological efficacy. These factors could include investigating factors such as the integrity of the nervous system and the severity of neurological disease. With Alzhimers and Parkinsons does early treatment allow for more promising neural technological results? However with neurological disorders that don't progress in "stages", researchers should evaluate the anatomical region of stimulation. Can stimulating one area of the brain result in effect in another. Researchers should also account for the role of gray and white matter as a factor of neuroplasticity in the brain. Any physiological factor may affect the efficacy of neurotechnology.

Neuroplasticity is something that researchers have always investigated but neurotechnology is quite a new field of exploration. Neurotechnology is very dynamic in nature, so anything that can supplement its nature will work to increase the benefits of the technology. So combining the old and new can only result in positive outcomes and the minor setbacks and side effects are overlookable because of the tremendous value of the collaboration. To summarize, neuroplasticity is a factor that can influence the efficacy of neurotechnologies. It should be considered when developing new types of instrumentation and treatment plans should account for the variability that this correlation brings.

Final Words

The world is a place where technology is now a major factor in every single human's life. One must adapt and innovate to the current climate. Innovation in technology is key to the advancement of human kinds. Specifically, innovation in medicine can lead to groundbreaking principles of development. Neurotechnology is just one facet of medical innovation. However, neurotechnology is a facet that will become more common in the coming years. We as a scientific community must ensure that this technology is perfected before it presents itself to patients who are in a situation of life and death.

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