Neural Implants Through Deep Brain Stimulation: Extracting the Science from Science Fiction

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Memory Enhancement Through Neural Implants and Deep Brain Stimulation

Memories are critical to individual identities and internal biographies, thus the loss of memory can often feel like a loss of self. Despite profound advancements being made in the field of neuroscience, tools for memory enhancement are more so subjects of fiction rather than science. Is it possible to draw inspiration from the cybernetic surgeries and memory-improval programs of science fiction tales to design modern-day research studies? This proposal explores the ideas from William Gibson's short story *Johnny Mnemonic* to develop a project that utilizes neural implants through deep brain stimulation to substantially improve memory enhancement and memory retrieval. Analyses of science fiction and scientific literature reveal the benefits of both internal intervention and external support in memory consolidation to allow for the efficient expansion of storage and organization of information in the human brain.

Before diving into the findings of recent scientific research, it is important to highlight the central theories of Gibson's science fiction piece. The story of *Johnny Mnemonic* follows the life of a data trafficker by the name of Johnny, who undergoes cybernetic surgery to implant a data storage system in his brain for memory enhancement. Corporations, wealthy individuals, and underworld crime rings utilize Johnny's advanced storage system to transport sensitive information to and from each other. Although he is able to store incredibly sensitive and copious amounts of digital data, Johnny has no knowledge of the content being stored in his brain and has no way of retrieving such by himself. The individuals that employ Johnny's services are the sole bearers of access to the passwords necessary to retrieve what is being stored in the data trafficker's brain. Throughout the short story, Johnny is fighting and running to free himself from the powerful people who are taking advantage of his enhanced memory. He decides that the best way to free himself is to acquire the necessary tools to extract the data being stored in his brain.

Through many trials and tribulations, Johnny is able to successfully access all that is being stored in his implanted storage system; ultimately, he uses the information he retrieves to blackmail the very figures who manipulated him. Johnny is able to recover past memories, however they are not memories that are personal to him. He expresses at the end of the short story, “One day I’ll have a surgeon dig all the silicon out of my amygdalae. And I’ll live with my own memories and nobody else’s. Like the way other people do” (Gibson, 1981). Johnny’s thoughts reflect the significance of memory on an individual’s identity—moreover, they suggest a necessity to develop an apparatus that allows for efficient expansion and retrieval of memory. Is this sort of innovation possible? Current research with deep brain stimulation suggests a strong likelihood.

Mnemonics, which are devices like acronyms, rhymes, or imagery, assist in the easy retrieval of information from memory. As such, it is quite ironic that the main character of Gibson’s short story, Johnny Mnemonic, possesses such incredible abilities to store memory, but lacks the necessary capacity to consciously “remember” any collection of information. This sparked the main argument of this research proposal, as we found ourselves asking, “How can data storage be expanded in the human brain and how can individuals organize and easily retrieve information being stored there?” Moreover, there was the question of what means would be most productive in achieving these criteria. Exploration of internal procedures (like deep brain stimulation) and external assistance in memory enhancement (like Neuralink) revealed the benefits of both methods in improving cognitive function.

In a study conducted by Suthana et al. (2012), a comparison of deep brain stimulation of the hippocampus to the deep brain stimulation of the entorhinal cortex revealed the successful alteration of memory performance by the latter. The medial temporal structures, including the hippocampus and the entorhinal cortex, are critical to the ability to transform daily experience into lasting memories. Researchers from this study performed an implantation of intracranial depth electrodes in seven subjects and then instructed them to complete a spatial learning task. Analysis of results revealed that despite the ineffective performance of direct hippocampal stimulation, entorhinal stimulation largely enhanced memory of information when applied during learning. The benefits of deep brain stimulation were further highlighted by researchers Suthana and Fried (2013), as their analysis of recent literature revealed the success of deep brain stimulation in enhancing memory related to facts and events dependent on the medial temporal lobe. The location, parameter, and phase of the delivery of deep brain stimulation have a substantial influence on its efficiency, thus researchers emphasize that a system that incorporates both continuous and on-demand stimulation, to the proper area of the brain, during periods of critical processing can be largely beneficial. Individuals with mild symptoms of Alzheimer's Disorder showed improvements in memory consolidation and slowing of cognitive decline after deep brain stimulation of the memory circuit involving the entorhinal and hippocampal areas (Laxton et al., 2010). These findings suggest that deep brain stimulation can be successful in memory enhancement and memory retrieval in both healthy and neurologically impaired individuals. Another study highlighted the benefits of deep brain stimulation in the bilateral hypothalamic region; interventions evoked detailed autobiographical memories and increased recollection (Hamani et al., 2008). Researchers found that hypothalamic deep brain stimulation drove activity in the medial temporal lobe structures for improved memory performance. Overall, the conclusions of scientific research reveal that the methods of memory enhancement proposed in Johnny Mnemonic are indeed possible to apply in reality.

While the science-fiction premise of Johnny Mnemonic's enhanced memory system through an internal medium using neural implants proved to be an appealing point to bridge the science and fiction of this proposal; we encountered a line of questioning that proved to become hurdles in designing this study. These hurdles as discussed previously, surrounded pragmatic approaches of where this implant would be placed, how it could be used to enhance memory, and whether or not this process would occur solely internally or with external means as well. In our investigation of the empirical literature exploring the effects of deep brain stimulation on memory performance, we were able to address and identify both where and how this implant could enhance memory. However, all of the empirical literature pointed to the necessity of using an external machine as well as a technician to cue the machine's actions. In order to utilize both the premises from both Johnny Mnemonic and our empirical research we looked to a promising development of modern technology that could fill this gap of communication between the internal implant and external stimulation machine so an individual could instead trigger the stimulation as needed.

This science fiction theme of human cognitive enhancement through implants is actually being researched under Elon Musk's project Neuralink. Neuralink is a neurotechnological corporation that's working on the development of implantable brain-machine interfaces ("Breakthrough Technology for the Brain," 2017). One of the current goals for this technology is to help people with paralysis regain independence and gain greater autonomy through the control of computers and other mobile devices hooked up to this neural implant. These neuralink devices are being developed in the hopes of giving people with neurological disorders that limit their physical mobility detail-oriented abilities. Neuralink if focusing particularly on activities that require fine motor movement; such as communication, searching information on the internet, and even creative outlets like digital graphics and photography all through text or speech synthesis ("Breakthrough Technology for the Brain," 2017). Essentially, the focus of Neuralink is to make activities that require motor functioning, such as typing, more accessible for physically disabled individuals.

As this technological project presents an intermediate approach in which the brain can communicate with a digital interface, we felt that it was the most reasonable avenue to use as the 'middleman' in our proposal. If applied, these Neuralink chips could be programmed to relay actions between the executive processing within the frontal lobe and the deep-brain stimulation machine to trigger responses in the implant placed in the entorhinal cortex. In order to enhance memory, which is the fundamental goal of our project, it is essential to uncover which part of the brain should be stimulated for ideal results. Johnny Mnemonic mentions the implantation of a tool in the amygdala, while scientific literature focuses on the entorhinal cortex in the hippocampal memory system. Though the amygdala is largely involved in memory consolidation, stimulation in the entorhinal cortex would likely be the most effective in enhancing memory based on the findings of modern scientific research. Though a relatively new concept, there have been notable findings in the advantages and limitations of deep brain stimulation. Despite the possibility of severe side effects and discrepancies in ethics and dependency, simulations have proven to successfully enhance motor and cognitive function.

Method

Participants

Participants in this study will include a sample of neurotypical individuals (N = 400) divided into two groups, control (Group 1A and Group 1B) and experimental (Group 2A and Group 2B). These participants will be divided again by age into groups ranging from 18-40 years old (Group 1A and Group 2A) and 51-70 years old (Group 1B and Group 2B). These age groups will address the age-related decline in memory performance that occurs at the average age between 45 and 57 years old in females and males (Park & Festini, 2017). The age groups within the control and experimental studies will be equally representative of gender (50 females), race, academic attainment, and economic background to avoid socioeconomic impact factors in collected data and findings. Participants will all be without visual impairments, and if so will be required to wear corrective lenses during the trials when completing learning tasks. As this proposal addresses memory performance, all participants must be without learning disabilities, no prior history of brain traumas, and will be average in their relative reading skills and comprehension.

Materials

The materials for this study proposal will be identical throughout testing completed between participants in Group 1A and Group 1B as well as Group 2A and Group 2B. All participants will answer socio-demographic questionnaires pertaining to their biological, social, and economic factors. Only participants in the experimental groups (2A and 2B) will receive the surgical implant and stimulation, but both groups will use a computer with a programmed virtual environment which will be implemented when participants undergo the memory learning task portion of the study. The virtual environment will consist of spatial stimuli and include landmarks, directional indications, and other geographical markers that the participants will study and familiarize themselves with. Both groups will complete a post-test to measure the accuracy and amount of information they retained from the learning task.

The following materials are specific to only Groups 2A and 2B. A magnetic-resonance imaging machine (MRI) will assist in the surgical placement of the entorhinal stimulatory implant. A Neuralink chip specifically programmed to interface between the stimulative implant, frontal cortex, and deep-brain stimulation machine will be surgically implanted within the relevant structures as its main processor is externally posed atop participants' head at the dorsal intersection of the sagittal and coronal axis. The entorhinal electrodes will be encoded with platinum contacts in order to observe the electroencephalogram (EEG) patterns, trigger stimulation, and pair with the Neuralink chip. These electrodes will send current-regulated impulses at regulated thresholds to avoid an intense-signal environment. An external neurostimulator will be connected to receive messages from the Neuralink as well as send electric signals to the entorhinal implants to trigger stimulation.

Procedures

Group 1. These subjects will only undergo the hour spatial learning task during which they will learn destination and other geographical markers in the presented virtual environment. To avoid expectancy feedback these participants will not be informed in advance of what is being measured after the learning task. They will be given general instructions to observe and try to memorize the virtual environment's locations and geography, but no directions which will allude to the act of being tested on this information after their hour session. After a 30-minute retaining period participants will then be tested on their memory of locations and markers from the learning task. Both groups 1A 1B will participate in these control trials.

Group 2. A similar method from researchers Suthana et al. (2012) will be used reflecting their implant and deep-brain stimulation procedures. However before the learning task for groups 2A and 2B trials, they will undergo the implant and Neuralink surgeries. These participants will be exposed to the same virtual environment learning task as the trials in Group 1. Similarly, they will also only be instructed to observe and to memorize the virtual environment's locations and geography, with no awareness of being tested on this information after their hour session. During their learning task, a regulated threshold of impulses will be sent from the neurostimulation machine to the entorhinal implant as cued by the activity detected and relayed to the Neuralink chip. After their trials, they will then complete the 30-minute retaining period. After this break participants will then be tested on their memory of locations and markers from the learning task. Post-test results from these Groups 1 and 2 will then be analyzed to compare the effects of stimulation vs. no stimulation on memory performance.

Discussion

Applications

If this study proves successful in demonstrating significant improvement in memory performance, the possible applications of this research could help progress a wide span of domains pertaining to the medical, professional, and academic field. Medically, this technology could be implemented in treatments to help delay age-related decline in memory, such as symptoms like dementia and diseases like Alzheimer's. With further testing to gain a deeper understanding of how neural structure plays a role in this process this treatment could also be used for victims of brain trauma that inhibits their ability to both store and recall memories as well as other cognitive functions.

For professional applications, this kind of technology could bring about the emergence of an instantly 'skilled' labor force. If people receive programmed memory training periods they could more efficiently become trained in their respective fields. Further testing would be required on semantic memory processing and the duration of memory enhancement.

Possibly the most appealing application lies within the educational domain. With an almost effortless way to enhance academic performance, this stimulation interface would reduce the time needed to review semantic information. Theoretically decreasing the amount of time needed to work on maintenance and committing this information to long-term memory. Similarly to the professional implications, for academic performance, further research would need to be conducted to observe semantic memory performance and duration of effect. However, with promising applications there exists even more limitations and consequences.

Limitations

Not only does this technology and memory enhancement process face medical and technological limitations but it poses philosophical, socioeconomic, and ethical concerns as well. As we have only the general knowledge from previous publications and ongoing research there are still many technical aspects that require complex processes and expertise in the medical and technical fields. While this proposal is based on theoretical findings pertaining to memory enhancement through stimulation, addressing the intricate details in the required surgical and programming aspects calls for further research and a stronger background in biology, computer science, and engineering. Despite the substantial obstacles these limitations pose, further research and collaboration could be conducted in order to explore the intricate aspects of this proposal until a workable solution is found.

Another consideration made in this technology's applications was its socioeconomic, philosophical, and ethical consequences. In applying this whole concept of effortless knowledge, learning is reduced to an even greater reliance upon socioeconomic status (SES) than the societal institutions do in today's world. Due to the complex nature of this proposal, the surgery and technology would be highly expensive. If it was used as an educational means, then it is also unlikely to be covered under any health insurance plan. Due to the cost of this procedure, this treatment would become largely inaccessible to individuals of lower socioeconomic status. Research has already shown that lower SES is directly linked to decreased educational success (McLaughlin & Sheridan, 2016.) With the grasp that socioeconomic status has now on educational attainment and competitive academic performance, this technology would only widen the monetary gap needed to succeed in an educational setting.

This effortless learning also plays a significant role in an individual's needs to achieve self-actualization. According to Maslow, we all have a hierarchy of needs and at the very top is the need to fulfill your full potential. With this technology, there would be a decrease in motivation due to the lack of effort in knowledge needed to accomplish both professional and personal goals. This effortless way to learn would significantly impact an individual's self-esteem and sense of self from a philosophical perspective. Philosopher Nelson Foote proposed a theoretical model of identity as the product of a circular relationship between motivation and one's sense of self where the two build off one another. The challenge of overcoming obstacles to both the self and their motivation is what allows these two to develop (Foote, 1951). As this stimulatory technology would reduce the challenges faced by individuals, their motivation and sense of self-identity would be significantly impacted.

In terms of ethical implications, one of the most pressing revolves around dependency in educational and professional settings. In education, this technology would significantly affect the competitive academic performance between both people who have access to this form of memory enhancement and those who would not. Being dependent upon this technology to increase performance is questionable due to the socioeconomic consequence discussed previously as well as the merit behind higher memory performance. In addition to academics, in a professional setting, would it be ethical to rely upon this technology with no real understanding yet of how long or successfully this treatment would assist in sustaining memory? As this form of technology within professional domains presents concerns of legal liabilities and an unclear efficiency of memory enhancement, it becomes increasingly apparent that the dependency individuals would form would be unethical and difficult to regulate. With these many limitations, greater discussion of how this memory enhancement would be applied in the real world is required.

Conclusion

If the results of this proposed study prove consistent with the findings of previous empirical research, then the data should demonstrate that not only does deep brain stimulation enhance memory performance (Suthana et al., 2012; Suthana and Fried, 2013; Laxton et al., 2010; Hamani et al., 2008), but also that this implant technology may assist in addressing age-related decline in memory (Park & Festini, 2017). In utilizing *Johnny Mnemonic*'*s* premise of memory enhancement through neural implants along with the real-life applications of deep brain stimulation and Neuralink chips, the bridge between science and fiction could be met in our study's proposed mechanism of a stimulatory interface to improve memory performance. While this proposal is founded upon accepted theoretical findings in our empirical literature review and the ongoing research under Neuralink, there still exists many limitations and consequences. Despite this technology's potential benefits in the medical, professional, and educational fields there still exists just as many prospective consequences. These implications call for further inquisition into the practicality and ethics of this neurostimulator technology to enhance learning and memory.

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