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Ethical Analysis of Brain Augmentation Through Nanotechnology

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Introduction

The nanoscale was first praised for its disparate nature by Richard P. Feynman in his famous 1960 lecture “There’s Plenty of Room at the Bottom”; he referred to it as a new field within physics, one with the unique properties of quantum physics and efficiency of bottom-up manufacturing. He even theorized that future surgeries would be performed by tiny robots within the body, a goal that is almost within reach of modern day researchers [1]. From this came the desire to observe and test the properties of compounds and elements at the nanoscale.

Nanoparticles can be composed of metal, carbon, ceramic, semiconductor materials, polymers, and lipids, each with a plethora of shapes and sizes within the 1-100 nm range [2]. Carbon, for instance, can be rolled into tubes with single or multiple layers, with or without branches, or manipulated to form hexagonal spheres; the spheres, or fullerenes, have incredible strength and electrical conductivity, while the tubes can be used as gas adsorbents and catalyst supports. They can also be utilized in tandem, such as having a polymeric core coupled with a lipid shell, to combine various desired traits [3]; the limitless combinations have facilitated breakthroughs in the medical, pharmaceutical, architectural, and even textile industries. Understanding the change in properties associated with size and shape has been studied to properly apply the structures to a function, providing scientists with an adaptable means of developing technology.

Nanotechnology has the capacity to change the pharmaceutical field by incorporating specialized delivery systems reliant on nano sized devices or capsules, changing the relationship between medical tools and drugs. The precision of nanostructures have allowed researchers to make significant breakthroughs with neural tissue growth *in vivo* and *in vitro*, as well as creating devices capable of interfacing with neural networks. This paper will discuss the ethics associated with brain augmentation by analyzing current technologies that fall under this classification and similar nanotechnologies in development, using a utilitarian lens to analyze the compounding changes these particles may have on society.

Common Brain Augmentations

Defining a brain augmentation can be a daunting task, with various viewpoints coming together to create a grey area. While some envision cybernetic implants replacing organs for increased performance, others would consider the biochemical benefits of exercise and proper nutrition as food for brain growth. Alternatively, some might see a casual game of sudoku as an amplification of their mental capabilities. This is where neuroplasticity and bodily maintenance

comes into play, rivaling the binary nature of computerized implants with the organic, neural complexity of the brain. Before discussing the innovative technologies that promise a better brain, it's important to acknowledge the many ways our species has maintained a heightened level of intelligence. The cognitive level of modern individuals supersedes primal instincts enough to suggest we are actively improving our minds throughout our lives. By defining these practices, and contrasting them with emerging technologies, we hope to give a clearer view of how brain augmentation through nanoparticles would be classified.

Education

The strongest form of brain augmentation is education; passing down information through the generations has lifted our species from primitive hunter gatherers to the pinnacle of Earthborn evolution. Training our progeny, and learning from peers and elders, has led to an elaborate form of intelligence molding known as schooling. The growing field of neuroscience allows us to map the brain and record patterns, letting researchers explore the minute changes that occur when we practice a technique. One group of scientists used whole-brain magnetic-resonance imaging to record brain waves and determine their association to specific behaviors. They taught individuals to juggle while recording their brain waves, with the goal of visualizing neuroplasticity in real time. During this experiment, they noticed structural and transient changes in the brain regions responsible for processing and storing complex motion [4]. This suggested a physical change in brain topography, or learning-induced plasticity, through an external stimulus. Physical changes occurring in the brain could be considered an improvement, albeit one that is accomplished through non-invasive and non-pharmacological techniques, warranting its status as the primary method of improving our intelligence.

Recreation

Certain behaviors or activities might not be viewed as educational, yet they still provide our brains with constructive stimuli. To the brain, there may be no difference between self-learning and being taught by another; one experiment chose to explore the effects of performing repeated tasks without instruction. These researchers had participants play Super Mario half an hour a day minimum for thirty days, monitoring their cerebral structure throughout the trial. Considerable increases in grey matter were noticed in the right hippocampal formation, right dorsolateral prefrontal cortex, and bilateral cerebellum; these indicated a transition from egocentric navigation techniques towards allocentric ones, while the volume of grey matter increase was correlated with the participants' desire to continue the task [5]. These topographic changes in the brain can be more specifically associated with strategy formulation, working memory, motor skills, and navigational skills, showing a clear improvement to the subject's mental capabilities through an external stimulus. Like education influencing neuroplasticity, repetitive tasks coupled with motivation, like video games, can have significant effects on the brain.

Nutrition

Eating fish because its brain food, or taking a walk to clear the mind, are common tropes seen amongst health-conscious individuals. The merits of eating healthy cannot be denied, and their influences on the brain and, subsequently, intelligence, are significant. A study that explored nutrients and their effects on the brain and cognition identified various compounds that can augment or hinder brain function. Flavonoids, for example, have been shown to enhance cognitive function in the elderly, whereas saturated fats have shown opposite effects [6]. These augmentations may be viewed as maintenance rather than improvement, but it's important to consider the longevity and fragility of neural networks in the brain; improvements may only be possible with proper nutrition, showing both preventative and constructive avenues towards intellectual growth. Diseases like Alzheimer's, where neurons have lost the insulation needed to fire properly, are a great example of nutritional maintenance correlating with brain augmentation; the natural loss of myelin sheaths on neurons can be remedied by the addition of beneficial omega-3 fatty acids in one's diet. Exploring the traditional methods of mental providence, and how they relate to physical changes in the brain, provides a depth of understanding necessary for the evaluation of ethically questionable nanotechnologies.

Exercise

Inducing positive brain changes through neuroplasticity and healthy living can be expanded to include exercise as a tool. Working out contributes to both mental and biochemical health by forcing the individual to focus on a strenuous task, providing a stimulus to the brain and the body. Research shows that cardiorespiratory activity can contribute to the augmentation of brain structure while reducing the loss of both grey and white matter brain tissue [7]. Additionally, these regions of the brain are associated with memory and cognitive ability, providing a precise correlation of topographic changes in the brain with the resulting behavioral alterations. It's also suggested that immediate brain function was improved through cardiorespiratory activity, providing a short-term benefit which may have compounding effects on overall cognitive growth. Considering the benefits of exercise, and its how those contributions are translated to brain topography, is necessary when looking at how nanotechnology will be applied to the brain. Using it as a model for healthy cognitive growth would be useful for the efficacy and precision of augmentative nanotechnologies.

Drugs

Pharmaceutical routes of improving brain function are becoming increasingly significant, with many behavior-altering compounds already integrated to everyday life. Stimulants like caffeine and methylphenidate are commonly used for focus, or treating focus disorders. Lately, prescription stimulants have been increasingly used by students without mental illness for their 'intelligence-boosting' effects. Studies have shown that this class of drug can improve declarative memory, with the potential to improve upon memory consolidation [8]. Interestingly, research has trended towards trials on people without attention disorders, with results that

suggest cognitive enhancement is also achieved by healthy individuals. While the effects of stimulants do mitigate the symptoms of an attention deficit disorder, they also improve prefrontal-dependent actions in the brain, allowing for augmentative applications. Other drugs have shown potential for brain augmentation as well, such as ampakines, which were designed for Alzheimer treatment but show potential for enhancing intelligence. They act by binding to glutamatergic AMPA receptors, causing it to ramp up activity by decreasing its sensitivity; this leads to an increase in synaptic responses and improves upon long-term potentiation function [9]. While the FDA has not approved any ampakines, their potential for cognitive enhancement and memory preservation is being explored by both military contractors and non-government labs. These noticeable trends in pharmaceuticals previously used for symptom prevention may lead to a new definition, or revolution, between treatment and augmentation through drugs.

Targeted Nanocapsules and Neuromodulation

Nanoparticles have the capacity to change how drugs are delivered, altering their strength, side effects, and applications. Using the novel attributes of nano-scale molecules, many drugs can be delivered to specific targets in the body, as well as allowing for increased permeability; additionally, they can be programmed to release the drug through time or stimuli based parameters [10]. The mechanisms can range from controlled chemical reactions acting as an engine to magnetic particles being manipulated via an external signal, showing diverse techniques stemming from various scientific fields. These technologies significantly augment the benefits of drugs while limiting side effects, making the interactions with our bodies more constructive.

Neuromodulation and the Blood Brain Barrier

Manipulating the brain to treat psychological disorders can be dangerous work, and reducing invasiveness is ideal for recovery. Generally known as neuromodulation, this can be done through drugs as well as applied electric stimuli. The implants required to facilitate electricity treatments can be harmful to the body, and many drugs can't cross the blood brain barrier, making it difficult to develop efficient treatments. Many studies have been done on the development of nanocapsules capable of transporting drugs across the blood brain barrier; one such technology utilizes external ultrasonic waves to release the drugs from the nanocapsules [11]. Another uses polymeric nanoparticles coated with either covalently attached targeting ligands or plasma-protein associated surfactants, allowing for receptor mediated uptake in to the brain [12]. These unique nanoencapsulation technologies can be employed to increase drug permeability and targetability, providing a highly adaptable delivery system for any drugs that influence the central nervous system directly. Additionally, their usage in rat trials has shown the capacity to treat seizures immediately with high uptake of drugs and no side effects.

Metal Nanoparticles for Brain Stimulation

While drugs are prevalent in treating disorders involving the central nervous system, non-pharmaceutical options are possible because of the electrochemical nature of neurons. Rather than inducing specific firing patterns through drugs, stimuli such as electricity and magnetism are focused on the brain. For example, deep brain stimulation (DBS) involves implanting electrodes within the brain and a power source under the skin, allowing the patient to receive constant electrical signals to specific brain regions; these signals induce firing amongst neurons near the electrode [13]. While DBS has been proven as neuromodulation techniques, it requires a physical connection to the patient and are limited by the focus of the device. To combat this, researchers have developed a method of neuromodulation without implants or drugs. Iron oxide nanoparticles at the 22nm range were equipped with polymeric coating to increase biocompatibility and dispersion, then injected into the mice; the size of the particles and properties of the coating allowed them to cross the blood-brain barrier. Once in the brain, researchers exposed the rat to focused external magnetic fields (EMF) to induce magnetothermia. The heat from magnetothermia can be used to force TRPV1 neurons to fire, and can be turned on or off indirectly through the EMF device. Additionally, the study showed that the nanoparticles remained in the brain for up to a month [14]. This provides a non-invasive, non-pharmaceutical, and long-lasting method of neuromodulation through inexpensive materials.

Growing, Augmenting, and Decoding Brain Tissue

Nanotechnology has also been applied towards neural treatments through drug-free alternatives involving stem cells, capable of inducing tissue regeneration *in vivo* and *in vitro*. Often times brain trauma results in tissue loss, leading to literal holes in the grey matter that aren't naturally healed by the body. Damaged or separated brain regions can pose many psychological and physiological issues, affecting the central nervous system and cognition of the individual [15]. Designing treatments that combat the physical problem rather than the symptoms would allow this technique to be applied to a broad range of brain disorders. Similarly, creating devices capable of performing the function of lost brain tissue, at the same capacity or improved, would create opportunities to both treat and study the brain and its compatibility with bionic devices.

Regenerating Neurons

While stem cells have been proven to treat illnesses involving tissue degradation or loss, the complex nature of cell potential, as well as the conditions needed to properly induce differentiation, make them difficult to develop. For instance, if neural stem cells developed improperly, glial cells could be formed instead of network-forming neurons. The potential to cause improper tissue growth has led many scientists to seek the precision of nanoparticles. One group of researchers has developed a method to regenerate the brain matter in these holes within

the body by using a self-healing hydrogel embedded with neural stem cells. After the gel is set in a shape, it can be drawn into a syringe and retain its shape after injection; it does this through nanoscale interactions between the individual components of the hydrogel. The hydrogel is set to fit a gap in a patient's brain, loaded with neural stem cells, and injected directly; as the stem cells develop into mature neurons, the hydrogel is degraded, leaving a complete neural network behind [16]. While this was developed to treat loss of grey matter, it could conceivably be used to treat underdeveloped brain regions, or even augment them. Culturing tissue outside the body is another method of growing neurons, but the three dimensional structure of brain tissue is difficult to reproduce, resulting in improper cell differentiation and linking. The difficulty in creating a three-dimensional scaffold for neuron growth with the same proportions and attributes as brain tissue has been surmounted through the nanowires. These structures can provide electrical signals necessary for the development of neurons and various muscle cells, as well as monitoring pH and standing as a free structure [17]. This is a huge step towards the development of stem cell treatments for brain disorders, as well as furthering our knowledge of neurons and how they can be integrated with machinery to create improved tissues. Developing cybernetic augmentations capable of melding organics with artificial intelligence is dependent on our understanding of neurons, how they fire, and how neural networks are formed.

Computer Brain Interfaces

As scientists unravel the electrical properties of neurons, and how the brain perceives and organizes these signals, studies have begun to interface the brain with computing devices. While cochlear, retinal, and epilepsy-treating implants are widely used and can be considered neural implants, they lack both nanoscale technology and cognitive immersion. Implants that interact with the regions of the brain responsible for memory are being increasingly studied on; one group of researchers have created a neural prosthesis with the purpose of restoring or augmenting memory. The device uses the information within the brain, analyzes it, and mimics it with electrical stimulation to restore the relay of information from that brain region [18]. Trials on rats have shown considerable success, implying that memory-restoring prosthetics may be developed, once scientists have a comprehensive understanding of the neural language. Other forms of implants that can precisely monitor brain waves are of interest as well. Recently, scientists developed an electronic mesh that can be injected to the brain for a variety of uses. It monitors neurons at the nanoscale, allowing them to monitor brain waves *in situ* and *in vivo*, bridge regions of the brain that have been separated, and relay the level of mechanical stress back to the researchers [19, 20]. This could be applied to disease prevention, research on brain wave pattern, and even the integration of neural implants with precise regions of the brain. Being able to bridge regions of the brain without surgery could also provide a non-invasive alternative to emerging tissue regeneration treatments. Alternatively, the ability to monitor brain waves could be applied towards P300 studies. P300 waves are associated with recognition; it could be likened to the feeling you get when you recognize someone's face. One study tested this by having individuals steal an item from a set of items, then recorded their brain waves while showing them a visual

display of all the object. A significant P300 signal was correlated with the subject being shown the item they stole [21]. These involuntary associations are trackable in the brain and can provide in-depth information about a person's likes and dislikes; integrating the patterns associated with P300 waves could allow us to augment memory retrieving skills, or perhaps gauge an individual's preferences indirectly.

Decoded Neurofeedback

While more research on brain wave patterns need to be done to truly decipher them, technologies have already been developed that can record a task-associated brain wave and transfer it to a separate individual. Known as decoded neurofeedback, it allows information to be shared without personal contact. Using functional magnetic resonance imaging to monitor brain waves, trial participants learned to control their brain waves in a specific way while the information was fed to other participants; after a few days, the results indicated an improvement in perception that was related to the task performed by the original participants [22]. Being able to convert a person's mastery of a skill, or muscle memory, to a format that can be instilled in a brain could improve on education exponentially, allowing anybody to learn the recorded task. Alternatively, it could be used to record someone at their peak prowess, allowing them to access that level of mental proficiency later in their lives. Similarly, intellectual preservation of the elderly and disabled could end mental deterioration, allowing people to live rich and productive lives. Another study used a similar method of information analysis and re input to teach rats short-term memory tasks. Information gathered from rats already proficient at the task were delivered through the internet and translated in to electrical stimulus used on new rats [23]. These rats, who had never performed the task, were now as proficient as the memory-donor rats, showing a successful assimilation of hippocampal firing patterns with the brain.

Ethical Implications of Brain Augmentation

Noting the spectrum of ways in which the human brain can be augmented, ethical issues regarding nano brain augmentation specifically overlap to an extent with the more traditional ways of achieving brain augmentation. That being said, nanotechnology pushes the envelope further and increases the realm of possibility when thinking about brain treatment and enhancement. We examine the ethics of nano brain augmentation using a utilitarian framework when possible and speculate problems that could arise in the future. Specifically we look at the ethics regarding health and safety, social justice, privacy and autonomy, humanness, and speculate into the future of human life.

Health and Safety

The potential health risks and benefits to nano brain augmentation is the first consideration from an ethical perspective. A novel problem that surfaces immediately is our lack of knowledge on the long-term effects of nanoparticle and nanomaterial accumulation in the body. The precise targeting of nanoparticles used for drug delivery and their minimal size for

minimally invasive procedures are among the salient benefits in using nanomaterials [10]. However, the differences in chemical behavior and evidence of adverse side effects in the body from nanoparticles weighs in on the balance of risk and benefit [2]. This issue is common among most medical treatments that pose a high potential benefits with common side effects as well. So when it comes to risk-benefit analysis of nanomaterials, especially in drug delivery, we must compare the risks associated with nanoparticles and the eliminated side effects from drugs.

Aside from the components of nanotechnologies for brain augmentation, the higher degrees of brain augmentation may pose benefits of increased memory and intelligence, but also place healthy subjects under unnecessary risk when undergoing elective brain augmentation. Obviously, there are elective procedures like cosmetic surgery that pose unnecessary health risks to patients, but these procedures do not involve altering the brain of a human that could fundamentally change the identity of a person [24, 25, 26]. Problems of informed consent stem from this issue [25]. How can a person consent to elective brain augmentation if they take on an alternative identity after the procedure has been done? When brain augmentation is applied for treatment purposes, is the risks of altered identity worth trying to cure a mental illness or neurological condition?

Based on the risks posed by the use of nanomaterials and the implementation of brain augmentation in human subjects, new regulatory measures should be taken. Current regulations regarding nanomaterials are mainly based on size limitations, but further research should be done to determine long-term effects of nanoparticle accumulation. Also, human subjects used in trials should mainly be for treatment purposes only as the unnecessary risks posed to healthy subjects, we feel, exceed the possible benefits of brain augmentation.

Social Justice

As nanotechnologies begin to penetrate the field of healthcare and progress further, we explore possible effects on local and global justice. Due to the extensive funding for research and development in nanotechnology, the problem of overall accessibility arises [26]. Wealthier countries are likely to have brain augmentation nanotechnologies more readily available relative to poorer countries. Inequality is a pressing issue as it is today and nanotechnology has the potential to fuel the issue. With greater accessibility in wealthier countries comes greater implementation and implantation of brain augmentation could expand the global divide further [25]. Also contributing to the global divide would be the greater likelihood of wealthier countries developing newer more advanced technologies as well.

Within wealthier countries exists socioeconomic inequality amongst individuals too. People of higher socioeconomic status would most likely be the initial segment of the population to be able to afford expensive brain augmentation procedures [26]. If brain augmentation can increase one's ability to reach greater socioeconomic standing, then inequality will increase locally in addition to the ever increase global divide. Thus, even if these nanotechnologies are accessible to the mass population, the affordability of brain augmentation could prevent low and middle-class people from taking advantage of the technology.

However, the implications on local and global inequality is under the assumption that mere access and affordability determine whether a person is able to obtain brain augmentation. However, since many nanotechnologies are targeted toward medical treatment rather than enhancement, it brings up the question of whether or not this distinction will have an effect of who is able to receive brain augmentation in the first place. This leads to a foundational ethical issue of how we define treatment versus enhancement, a distinction that is by no means clear cut and not a novel discussion [27, 28, 29]. For instance, prescription drugs like adderall and ritalin used for the treatment of patients with ADHD can easily be considered a form of enhancement when used by individuals who are not prescribed the drug. ADHD medications have been shown to increase productivity in people without ADHD, and thus has been widely used in competitive academic environments to enhance normal cognition [27]. Drugs and nanotechnologies developed as medical treatments can easily be converted to a form of cognitive enhancement, thus, illustrating the blurry boundary between treatments and enhancements.

That being said, many would consider the use of drugs like Adderall for cognitive enhancement an unethical action. Nanotechnologies for brain augmentation expands on this discussion based on the breadth of technologies currently available and others in development. A great deal of nanotechnologies for brain augmentation act as treatments for things like brain tumors, neurological conditions, and physical disabilities. An injectable scaffold for increased neuron growth in a damaged area of the brain can be turned into an enhancement when injected into a healthy human being for an increased neuronal network [17]. Aside from potential treatment technologies, nano brain augmentation stems into uncharted territory when considering applications for enhancement purposes only [26, 30]. Whether we consider brain enhancement to be ethical is obviously subject to debate. One take on this issue suggests cognitive enhancement through nanotechnology should be viewed as just another way that our uniquely innovative species tries to improve itself [31]. For this perspective, an individual using education, exercise, and good nutrition as modes of cognitive enhancement are ethical, and thus, cognitive enhancement in general should be considered ethical as well. On the other end, nanotechnology for brain enhancement could be seen as unethical to people who view it as a means to gain an unfair advantage over the general population.

In consideration of nanotechnologies for medical treatment through brain augmentation, we believe they will only be accessible to people with the need for medical treatment. Just as drugs are medically prescribed as treatments rather than enhancements, nanotechnologies for treatment purposes may only be accessible in this fashion and limit the inequality issues posed prior. However, when thinking about nanotechnologies in development for brain enhancement such as computer chips for increased memory, limiting access to these technologies would be unfeasible as they directly oppose the purpose for the development in the first place. From this, the inequality issues locally and globally come into play and could have extensive effects on driving the wealthy into an even more prestigious class while leaving everything else worse off [25, 32].

These issues, we see, as more immediate effects of brain augmentation. However, there is a possibility that brain enhancement nanotechnologies could lead to decreased inequality in the more distant future. For instance, the unequal access to higher education in developing areas of the world creates a sort of poverty trap. Wealthier countries have greater access to higher education and thus, have people that can improve their intelligence with the resources available. Closing the gap in education between the developed and developing world has been difficult due to the high costs, but if brain augmentation nanotechnologies become affordable over time and available to everyone, whether it is paid for or subsidized, brain augmentation procedures could eliminate the need for higher education since the knowledge could be given to people in developing countries with one procedure. Overall, this would level the playing field in terms of available information among people to pursue interests rather than just survive.

The initial unequal distribution of nano brain augmentation could also lead to discrimination between those with and without brain augmentation [32]. People without nano brain augmentation could view people with it as having an unfair advantage. On the other end, people with brain augmentation may view non-augmented people as inferior. This could have serious implications in the workplace especially if people with augmented brains are more desirable, thus having greater access to higher level jobs [32].

Privacy and Autonomy

The surface level issues of limiting access to brain augmentation bring human autonomy into question. If we consider complete autonomy as something that should be had by all humans, then people should be able to choose if they want an augmented brain or not. Restricting access to certain people and allowing access to others infringes on individuals' control over their own body [33]. Also, the discrimination between those with and without brain augmentation would only be possible if information is publically available on who has nano brain augmentation. Should information like this be kept private, or would people with brain augmentation make the information known to employers as an asset that they would bring to the job?

However, these issues of autonomy and privacy are superficial in the grand scheme of things. Implanting nanotechnologies into the brain that can track thoughts, experiences, and overall brain activity invades a person's privacy at a much deeper level [33]. Who would have access to the information recorded by the implanted devices? The individual with the implant should be able to access all of the information collected on them and should be able to control who else has access to it as well. However, this most likely will not be the case. A simple comparison is our cellphones. While we hold much private information on our cellphones, the information can be accessed from the people who ultimately control our phones. Likewise, the people who developed the technology implant could have access to much more private information, that being a person's brain, rather than just cell phone data. Furthermore, if implanted computer brain interfaces can be hacked from an outside source, will that person be able to remotely trace and control the brain activity of a person with nano brain augmentation? While these questions may be somewhat farfetched based on the currently available

technologies, we do not think they are out of the realm of possibility, and thus needs to be considered by those who weigh the potential risks and benefits of obtaining brain augmentation.

Humanness

Nanotechnologies for brain augmentation are broad in scope including nano drug carriers, nanoscaffolds with cultured neurons, nano-bionic devices, and nano computer-brain interfaces. As we increasingly incorporate foreign materials into our bodies for various reasons, we may begin to question what it means to be human [29]. At what point does nano brain augmentation lead us to becoming more machine and less human? Nano-drug carriers do not pose much of an issue because they are just an addition to make drug treatments more effective. Nanoscaffolds cultured with neurons to incorporate into our neural network takes nano brain augmentation a slight step further by incorporating foreign matter. However, since it involves organic tissue as the main component with biodegradable nanoscaffolds, the ethical dilemma between man vs machine keeps humans nearer the man side and less machine. As we branch into nano-bionic devices that could increase synaptic activity, perform brain maintenance, or restore function to part of the brain, some may find this to be more unnatural, thus making a human being less human. We think these nanotechnologies would be ethically acceptable since there are non-nano brain augmentation devices like cochlear implants that are by no means natural, but are socially accepted. Cochlear implants did have a major paradigm shift in deaf culture and how we view deafness, but did not lead us to consider individuals with cochlear implants as something other than human [30]. The nano computer brain interfaces are amongst the most progressive methods for brain augmentation and is where the most pressing ethical implications for what being human entails. For instance, nanochips to increase intelligence, transfer and record thoughts, or modified carbon nanotubes to create artificial synapses in the brain fundamentally alter the way in which we conceptualize the brain [18]. Many consider the brain, consciousness, and emotion, to be key aspects to what make us human and impacting one or all of these things through nano brain augmentation may lead people to question what we are now what we could become [24].

We hypothesize that defining the the concept of humanness will be difficult once nano brain augmentation has the potential to copy and download a person's consciousness. Researchers suggest there is no reason why this would not be feasible in the future due to brain mapping technologies and current augmentation techniques already in development. They simply view the human mind as a complex computer that depends on electrochemical processes [34]. The major limitation to downloading consciousness is the computing capacity necessary to mimic the brain, however, with the doubling of computing power year after year, scientists believe computers will be capable of processing information as the brain does [34]. If and when this becomes available, the concept of humanness will need to be revised. If we are able to download consciousness, humans could ultimately become immortal, and live through many different bodies or machines. However, the implication of how new information would be absorbed after inputting a person's consciousness into another being or machine is difficult to comprehend. At this point, is human consciousness taken over by machines? Do humans

becomes trapped within machines unable to escape? Or do humans become immortal, retaining individual consciousness and roaming the earth until the end of time? These are science fiction type questions, but are questions that could be asked in the future and if they are, we could be looking at a fundamental change in the human species altogether.

Future Perspective

If nanotechnology continues to progress, the first problem that is likely to vanish is brain conditions altogether. Nanotechnology could develop new treatments or interventions to treat mental illnesses or cancers in the brain to the point where they become irrelevant issues to human life. Additionally, the adverse side effects from current drug treatments could be eliminated entirely in the future with nanoparticles for efficient targeted drug delivery, assuming nanoparticles do not have detrimental side effects of their own.

The elimination of incurable neurological conditions would most likely further motivate humans to pursue elective brain augmentation procedures for enhanced neural activity. Our brain capacity and potential could be improved exponentially with stronger synaptic connections, greater neuronal density, and nano computer chips to input and store knowledge in our brains that we had not previously learned.

Of course, if learning could be achieved instantaneously through uploading information to the brain, then education altogether will be antiquated. Would education even be necessary in society? Perhaps children would still go to school to interact with other kids and experience different topics to determine their specific interests, and then once defining their interests, their brains could be augmented to direct their future accordingly.

As a species that has always been motivated to improve ourselves, brain augmentation offers a mode of unfathomable improvement. We believe that eventually, the adapting and augmenting of our brains using nanotechnology will become the norm in society. Referring back the issue of what makes us human, rather than thinking brain augmentation makes us something other than human, it could be viewed as an accelerated evolutionary step that actually makes us human.

Conclusion

The development of restrictions and regulations on nanomaterials based on their safety and capacity for brain augmentation will be a defining moment for science. While incredible potential for drug modification exists, the long-term effects of nanoparticles on the body and the environment are largely unknown. Widespread usage of nano-modified drugs could scar generations of people with debilitating illnesses, like the thousands of malformed babies resulting from thalidomide treatment [35]. Bioaccumulation of these particles could endanger many species, like when DDT was introduced as a pesticide without understanding its disastrous effects on wildlife [36]. Similarly, the division between medical tools and drugs blurs as

nanodevices become capable of interacting with the body through non-pharmaceutical means like heat and magnetism. These changes may alter how pharmaceutical products are marketed and regulated, subsequently changing their availability between countries and socioeconomic strata. As neuroscience expands alongside nanotechnology, integrating machinery with the central nervous system has become increasingly easier. Implants capable of treating brain diseases may be expanded to increase intelligence and memory recollection, creating the need for regulations and a distinction between treatment and enhancement. This can be expanded to question the idea of humanity, and the extent at which cognitive modification changes the individual, thus fouling the role of consent in such procedures. One's individuality and their ability to consent would be change for both the doctor and the patient, making elective modifications an ethical quandary. Similarly, the advances in P300 signals have made the brain much more predictable, allowing for breaches in privacy on a cognitive level. Brain implants could be used to monitor various aspects of your thoughts and intentions, as well as discern information from you through recognition signals. Ideas and skills could be transferred through decoded neurofeedback to promote education, but also have the capacity to facilitate the theft of intellectual property. The exponential growth of technology emphasizes the need to characterize nanotechnology as a unique field while providing a specialized set of regulations with it to protect society and the environment.

References:

1. Feynman RP (1960) "There's Plenty of Room at the Bottom". Lecture, California, Pasadena. Accessed December 8th, 2017.
<http://calteches.library.caltech.edu/47/2/1960Bottom.pdf>
2. Khan I, Saeed K, Khan I (2017) Nanoparticles: Properties, applications, and toxicities. Arabian Journal of Chemistry. 2017.
<http://www.sciencedirect.com/science/article/pii/S1878535217300990>

3. Hu Y, Ehrlich M, Fuhrman K, Zhang C (2014) In vitro performance of lipid-PLGA hybrid nanoparticles as an antigen delivery system: lipid composition matters. *Nanoscale Research Letters*. 9: 434. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4154617/>
4. Draganski B, Gaser C, Busch V, Schuierer G, Bogdahn U, May A (2004) Neuroplasticity: Changes in grey matter induced by training. *Nature* 427:311-312. <https://www.nature.com/articles/427311a>
5. Kuhn J, Gleich T, Lorenz RC, Lindenberger U, Gallinat J (2014) Playing Super Mario induces structural brain plasticity: gray matter changes resulting from training with a commercial video game. *Molecular Psychiatry* 19(2): 265-271 <https://www.ncbi.nlm.nih.gov/pubmed/24166407>
6. Gomez-Pinilla F (2008) Brain foods: the effects of nutrients on brain function. *Nature Reviews Neuroscience* 9: 568-578 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2805706/>
7. Gomez-Pinilla F (2013) The Influence of Exercise on Cognitive Abilities. *Comprehensive Physiology* 3: 403-428. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3951958/>
8. Smith ME, Farah MJ (2011) Are prescription stimulants “smart pills”? The epidemiology and cognitive neuroscience of prescription stimulant use by normal healthy individuals. *Psychological Bulletin*, 137(5), 717-741. <http://psycnet.apa.org/record/2011-18633-001>
9. Urban KR, Gao W (2014) Performance enhancement at the cost of potential brain plasticity: neural ramifications of nootropic drugs in the healthy developing brain. *Frontiers in Systems Neuroscience* 8: 38. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4026746/>
10. Jong D, Borm P (2008) Drug delivery and nanoparticles: Applications and hazards. *International Journal of Nanomedicine* 133. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2527668/>
11. Airan RD, Meyer RA, Ellens NPK, Rhodes KR, Farahani K, Pomper MG, Kadam SD, Green JJ (2017) Noninvasive Targeted Transcranial Neuromodulation via Focused Ultrasound Gated Drug Release from Nanoemulsions. *Nano Letters* 17:652–659. <http://pubs.acs.org/doi/10.1021/acs.nanolett.6b03517>
12. Wolfhart S, Gelperina S, Kreuter J (2012) Transport of drugs across the blood-brain barrier by nanoparticles. *Journal of Controlled Release* 161(2): 264-273. <http://www.sciencedirect.com/science/article/pii/S0168365911005852>
13. Delaloye S, Holtzheimer P (2014) Deep brain stimulation on the treatment of depression. *Dialogues in Clinical Neuroscience* 16: 83-91 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3984894/>
14. Chen R, Romero G, Christiansen MG, Mohr A, Anikeeva P (2015) Wireless magnetothermal deep brain stimulation. *Science*. <http://science.sciencemag.org/content/early/2015/03/11/science.1261821.full>

15. Sauerbeck A, Gao J, Readnower R, Liu M, Pauly JR, Bing G, Sullivan PG (2011) Pioglitazone attenuates mitochondrial dysfunction, cognitive impairment, cortical tissue loss, and inflammation following traumatic brain injury. *Experimental Neurology* 227(1): 128-135. <http://www.sciencedirect.com/science/article/pii/S0014488610003882>
16. Wei Z, Zhao J, Chen YM, Zhang P, Zhang Q (2016) Self-healing polysaccharide-based hydrogels as injectable carriers for neural stem cells. *Scientific Reports* 6:37841. <https://www.nature.com/articles/srep37841>
17. Tian B, Liu J, Jin L, Tsui JH, Qing Q, Suo Z, Langer R, Kohane DS, Lieber CM (2013) Macroporous nanowire nanoelectronic scaffolds for synthetic tissues. *Nature Materials* 11: 986-994. <https://www.nature.com/articles/nmat3404>
18. Berger TW, Hampson RE, Song D, Goonawardena A, Marmarelis V, Deadwyler SA (2011) A cortical neural prosthesis for restoring and enhancing memory. *Journal of Neural Engineering* 8: 046017. <http://iopscience.iop.org/article/10.1088/1741-2560/8/4/046017/meta>
19. Liu J, Fu TM, Cheng Z, Hong G, Zhou T, Jin L, Duvvuri M, Jiang Z, Kruskal P, Xie C, Suo Z, Fang Y, Lieber CM (2015) Syringe Injectable Electronics. *Springer Theses Biomimetics Through Nanoelectronics* 65–93. <https://www.nature.com/articles/nnano.2015.115>
20. Zhou T, Hong G, Fu TM, Yang X, Schuhmann TG, Viveros RD, Lieber CM (2017) Syringe-injectable mesh electronics integrate seamlessly with minimal chronic immune response in the brain. *Proceedings of the National Academy of Sciences* 114: 5894–5899. <http://www.pnas.org/content/114/23/5894.full>
21. Rosenfeld PJ, Nasman VT, Whalen R, Cantwell B, Mazzeri L (1987) Late Vertex Positivity in Event-Related Potentials as a Guilty Knowledge Indicator: A New Method of Lie Detection. *International Journal of Neuroscience* 34(1-2): 125-129 <http://www.tandfonline.com/doi/abs/10.3109/00207458708985947>
22. Shibata K (2012) [A new neuroscientific approach using decoded neurofeedback (DecNef)]. *Rinsho Shinkeigaku* <https://www.ncbi.nlm.nih.gov/pubmed/23196557>
23. Deadwyler SA, Berger TW, Sweatt AJ, Song D, Chan RHM, Opris I, Gerhardt GA, Marmarelis VZ, Hampson RE (2013) Donor/recipient enhancement of memory in rat hippocampus. *Frontiers in Systems Neuroscience* <https://www.frontiersin.org/articles/10.3389/fnsys.2013.00120/full>
24. Jotterand F (2008) Beyond Therapy and Enhancement: The Alteration of Human Nature. *NanoEthics* 2(1): 15-23. doi:10.1007/s11569-008-0025-z
25. Lin P, Allhoff, F (2008) Untangling the Debate: The Ethics of Human Enhancement. *NanoEthics*, 2(3): 251-264. doi:10.1007/s11569-008-0046-7
26. Milleson V (2012) Nanotechnology, the Brain, and the Future: Ethical Considerations. *Nanotechnology, the Brain, and the Future*, 79-96. doi:10.1007/978-94-007-1787-9_5

27. Franke AG, Lieb K (2013) Pharmacological Neuroenhancement: Substances and Epidemiology. *Trends in Augmentation of Human Performance Cognitive Enhancement*, 17-27. doi:10.1007/978-94-007-6253-4_2
28. O'Mathúna, D (2010) Nanoethics: big ethical issues with small technology. *Continuum*.
29. Schermer M (2009) The Mind and the Machine. On the Conceptual and Moral Implications of Brain-Machine Interaction. *NanoEthics*, 3(3), 217-230. doi:10.1007/s11569-009-0076-9
30. Bostrom N, Sandberg A (2009) Cognitive Enhancement: Methods, Ethics, Regulatory Challenges. *Science and Engineering Ethics* 15(3): 311-341. doi:10.1007/s11948-009-9142-5
31. Greely HT, Sahakian B, Harris J, Kessler RC, Gazzaniga MS, Campbell P (2008) Towards responsible use of cognitive-enhancing drugs by the healthy. *Nature* 456: 702–705 10.1038/456702a
32. Nagel SK (2014) Enhancement for well-being is still ethically challenging. *Frontiers in Systems Neuroscience* 8. doi:10.3389/fnsys.2014.00072
33. Gilbert F (2015) A Threat to Autonomy? The Intrusion of Predictive Brain Implants. *AJOB Neuroscience*, 6(4), 4-11. doi:10.1080/21507740.2015.1076087
34. Inafuku J, Lampert K, Lawson B, Stehly S, & Vaccaro A (n.d.) Technology and Research. <https://cs.stanford.edu/people/eroberts/cs181/projects/2010-11/DownloadingConsciousness/tandr.html>
35. McBride WG (1977) Thalidomide embryopathy. *Teratogen Update* 16(1): 79-82 <http://onlinelibrary.wiley.com/doi/10.1002/tera.1420160113/full>
36. Colborn T, Saal FS, Soto AM (1993) Developmental effects of endocrine-disrupting chemicals in wildlife and humans. *Environmental Health Perspectives* 101(5):378-384 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1519860/>