# Chapter 11
# Nano-bionic Devices for the Purpose of Cognitive Enhancement: Toward a Preliminary Ethical Framework

**Frédéric Gilbert**

**Abstract** This chapter examines the emerging ethical challenges raised by implementation of nanotechnology in brain devices for enhancement purposes in subjects with healthy brains. This chapter will proceed in five steps. The first section introduces brain implants and discusses how their status may be changed by nanotechnologies for enhancement purposes. The second section explores whether the ethics of nano-bionic devices for cognitive enhancement purposes in healthy, informed subjects might be helped by referring to the treatment-enhancement distinction. Such a distinction could serve to illuminate guidelines and policies. The third section examines whether the designs for nano-bionic devices for cognitive enhancement raise a number of intrinsically new ethical problems if applied to healthy subjects. The fourth section looks at whether nano-bionic devices used for the purpose of enhancement introduce novel ethical difficulties to the informed consent of healthy and free subjects. The fifth section sketches the preliminary ethics that have to be established before a healthy individual could undergo an informed consent process for invasive nano-bionics brain intervention.

**Keywords** Cognitive enhancement • Nanotechnology • Brain implants • Ethics • Informed consent

## 11.1 Introduction

In recent years, treatments using brain devices have attracted great interest in the medical community, not only for their effectiveness in terms of treatment, but also for their potential future applications. In the near future, developments in medical

F. Gilbert (✉)
School of Philosophy, Faculty of Arts, ARC Centre of Excellence for Electromaterials Science (ACES), University of Tasmania, Hobart, TAS, Australia
e-mail: frederic.gilbert@utas.edu.au

E. Hildt and A.G. Franke (eds.), *Cognitive Enhancement: An Interdisciplinary Perspective*, Trends in Augmentation of Human Performance 1,
DOI 10.1007/978-94-007-6253-4_11, 

nanotechnologies have the potential to make these brain device technologies less invasive and more localized, less costly and more reliable. These possibilities will play major roles in the performance of the implants while expanding the safety and the range of applications (Andrews 2009). With these great hopes for nano-bionic devices, designed for the brain, come various ethical challenges (Berger et al. 2008).

Human brain implants can be described as surgically invasive devices. They are commonly used for the following treatments: to remediate various symptoms of innate or acquired loss of sensory functions (e.g. cochlear implants, retinal implants) (Andrews 2009); to restore movement in cases of paralysis (e.g. motor neuroprosthetics) (Kennedy and Bakay 1998; Hochberg et al. 2006); and to treat neuronal diseases (e.g. Deep Brain Stimulation implants). According to MEDTRONIC, the largest manufacturer of Deep Brain Stimulation devices, since 1995 over 80,000 people worldwide have been treated with their brain implants (Medtronic 2011). Additionally, as of 2009, approximately 188,000 people worldwide have received cochlear implants according to the U.S. Food and Drug Administration (Davis 2009).

Deep Brain Stimulation (DBS) implants are versatile and can be applied to many types of neurological dysfunction. The current applications of DBS treatments have targeted Parkinson's symptoms, such as tremor, rigidity, stiffness, slowed movement, or even walking problems. Others DBS applications include treatment for diseases, such as dystonia, cluster headaches, minimally conscious state, and phantom limb pain (Clausen 2010). The technique consists of implanting a battery-operated neuromedical device that delivers an electrical stimulation to a specific area of the patient's brain. DBS technologies have also been used to treat psychiatric conditions (most of them are still in the experimental phase), such as severe depression, obsessive-compulsive disorder, Tourette's syndrome, obesity, epilepsy, Alzheimer's disease, impulsive and aggressive behavior and addiction (Franzini et al. 2005; Kuhn et al. 2007; Heinze et al. 2009; Clausen 2010).

In terms of enhancements, Hamani et al. (2008) and Adrian et al. (2010) have reported serendipitous correlations between DBS and cognition (e.g. memory), while Berney et al. (2002) and Houeto et al. (2002) have observed positive mood modification (e.g. decrease in major depressive tendencies). In addition, Tsai et al. (2010) and Haq et al. (2010) reported functionality enhancements (i.e. increased libido). These discoveries have sparked great interest and speculation, especially with regard to future nanomedicine implementations.

Researchers are currently developing a set of new generation brain implants that use nanomaterials. A nanometer is one-billionth of a meter. The rapid expansion of nanomaterial for use in brain implants holds great promise. For example, biosensors, which are used for targeted drug delivery and as platforms for neural cell growth (Lee and Parpura 2009). Researchers at the Australian Center of Excellence in Electromaterial Science (ACES) have already engineered biodegradable polymers such as cortex drug delivery to treat epilepsy in rodents (Wilz et al. 2008; Halliday and Cook 2009). Moreover, members of ACES are also involved in the world's first-in-human trial using an "intelligent brain implant" with a seizure warning for epileptic patients. The brain implant can predict when an epileptic seizure will

occur (Snyder et al. 2008; NeuroVista 2011) and issue an alert. Current research at ACES involves the development of brain implants that can detect and deliver drugs for use in humans. These current applications allow us to consider seriously the expansion of applications of these devices to other neural diseases. It is quite possible to imagine, in the near future, the use of biodegradable polymers for cortex drug delivery associated with an intelligent brain device to treat various neuronal diseases or an intelligent brain implant that can predict and send warnings for other neuronal dysfunctions, such as the imminent onset of an aggressive phase, manic phase, addictive rush, etc. These future applications are still speculative; nonetheless, it is important to develop an ethical framework around such future development given that such treatment could directly affect how healthy individuals improve their well-being (Gilbert et al. 2012).

According to the constitution of the World Health Organization (1946), "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." The constitution adds that "the enjoyment of the highest attainable standard of health is one of the fundamental rights of every human." What if the use of nano-bionic devices could achieve the highest attainable physical, mental and social well-being? In others terms, what if one day, versatile brain implants using nanomaterials were not strictly reserved for treating patients with neurodegenerative diseases and psychiatric conditions? Given this possible extension of the uses of nano-bionic devices, it behooves us to ask: Is there something intrinsically unethical about using these devices for cognitive enhancement purposes in healthy, fully informed, free, consenting subjects? Why would nanotechnologically-based, human enhancement be morally impermissible if it respects the individual's right to choose for her own physical integrity?

## 11.2 Much Ado About Nothing?

What is enhancement? For its proponents, enhancement is merely a form of treatment which could help people be *better* rather than *well*. From a scientific point of view, it is not clear if any significant enhancement effects exist in healthy subjects (Repantis et al. 2008). To this unknown, there is an emerging literature that highlights the "exaggeration" regarding the use of cognitive enhancement (Partridge et al. 2011), exaggeration that has encouraged speculative assumptions that reduce ethics to approximate debate (Gilbert 2011). That being said, this section examines whether the ethics of nano-bionic devices for the purpose of cognitive enhancement in healthy, informed subjects might be helped by referring to the treatment-enhancement distinction, which could then serve to establish guidelines and policies for the legitimate use of such devices.

There are difficulties in precisely defining a distinction between enhancement and treatment with respect to nano-bionic devices. On one hand, the use of the concept of treatment is universally associated with ethical values: treatments are intended to restore health or to prevent sickness. On the other hand, enhancement

is a polysemic concept that has numerous uses in academic literature that are not necessarily associated with ethics. When the notion of enhancement is used in philosophy, ethical values feature prominently. For instance, transhumanism, a group of futurist philosophical theories, regards enhancement as "one of the most important and challenging issues of the new century" (Bostrom and Savulescu 2009); other schools of thought point out that, "the challenges of human enhancement" make it important to think about how research is conducted (Juengst et al. 2003). However, when enhancement is used in science, the concept refers to any amelioration of a state without reference to ethical value. This use can be illustrated by random academic examples such as "adenovirus enhancement" (Curiel et al. 1991); "enhancement of transfection efficiency of naked plasmid DNA in skeletal muscle" (Taniyama et al. 2002); "enhancement of secreted phosphoprotein" (Noda et al. 1990), etc. Under these scientific descriptions, the notion of enhancement does not involve any ethical value.

The use of the concept of enhancement in the above scientific examples is restricted to biomedical mechanisms. However, it has to be remembered that even in these restricted senses, ethical questions arise. For instance, if science has focused on enhancing one's genes that contribute to memory in particular, then, at the same time, science has also enhanced one's memory overall. The former use of "gene enhancement" may seem to have little ethical value, but the latter "memory enhancement" does raise questions of ethical value.

This analysis helps us to see that the treatment-enhancement distinction might be difficult to uphold (Harris 2007). However, one could still defend a traditional way of preserving the distinction by arguing that medicine should be limited to treatment and should not engage in enhancement. How strong is this position?

It is not a controversial claim to affirm that every treatment aims to enhance a certain state. It is the case that all treatments are legitimated only by the assumption that they are likely to improve a patient's quality of life. So, every treatment constitutes a form of enhancement somehow (Elliott 2003). To be sure, if a convincing line is drawn between the treatment (medical treatment to restore or preserve a patient's quality of life) and the enhancement of otherwise normal traits (clearly to improve normal functioning), this line would not coincide with what medicine is morally obliged to do or not do (Daniels 2000). Since treatment involves a form of enhancement, what would be ethically permissible versus impermissible may not be allowed by what exactly constitutes cognitive enhancement or treatment in terms of nano-bionic devices. To speak about the distinction between treatment versus enhancement is neither necessary nor helpful in order to find the appropriate ethical framework for the use of nano-bionic devices in healthy, informed and consenting subjects.

What really matters in ethics is not the question of whether every treatment is a form of enhancement, but rather, whether every enhancement is a form of treatment. A closer look at the universal argument, "every treatment presents a form of enhancement" (Synofzik 2009), reveals a major logical conflation. In fact, the argument is not sufficient to conclude anything about enhancement versus treatment since it does not necessarily imply that "all enhancement presents a form

of treatment." It is a logical conflation to derive the second proposition from the first. In fact, if "every treatment presents a form of enhancement," an argument such as, "some enhancements are not a form of treatment," is sufficient to demonstrate the logical fallacy of "every treatment presents a form of enhancement." For instance, somatropin (human growth hormone), used in sports, is not a form of treatment; it is, rather, only a form of enhancement.[1] From this proposition, it is possible to conclude that if not every enhancement is a form of treatment, then not every treatment is a form of enhancement. In other words, some nano-bionic device treatments could be presented as a form of enhancement but not all. The same conclusion is applicable for nano-bionic devices for cognitive enhancements purposes: some of them may be presented as forms of treatment but not all. This criticism of the argument does not modify our previous point concerning enhancement of healthy, informed subjects. The distinction between treatment-enhancement is not necessary. This distinction does not help to develop an ethical framework for nano-bionic devices, which could serve to steer guidelines and policies for their legitimate use in healthy individuals. The next section will examine whether nano-bionic devices raise new ethical issues.

## 11.3 Novel Ethical Issue?

Long before Drexler's 1986 book, *Engines of Creation: The Coming Era of Nanotechnology* (Drexler 1986), which anticipates the use of precise molecular assembly for a wide variety of applications in order to increase the quality of human life, meliorating the human condition through advances in technology had been debated. The debate can, in part, be traced back to the Enlightenment. Already, in 1795, Condorcet, in his "Outlines of an historical view of the progress of the human mind," asked whether the "human race should be meliorated by new discoveries in the sciences" within "the improvement of the instruments which increase the power and direct exercise of [moral, intellectual and physical] faculties."[2] Condorcet's question followed his assumption:

> No bounds have been fixed to the improvement of the human faculties; that the perfectibility of man is absolutely indefinite; that the progress of this perfectibility, henceforth above the control of every power that would impede it, has no other limit than the duration of the globe upon which nature has placed us. (de Condorcet 1795)

[1] I assume that enhancers have an enhancement effect in any body (i.e. a healthy body and a sick body). For instance, growth hormones affect any body, not only a body with disease. However, not all treatment will have an enhancement effect (i.e. a healthy body and a sick body). For example, could a treatment with radiation or a treatment for influenza enhance a healthy body?

[2] "L'espèce humaine doit-elle s'améliorer, soit par de nouvelles découvertes dans les sciences [...]; soit enfin par le perfectionnement réel des facultés intellectuelles, morales et physiques, qui peut être également la suite, ou de celui des instruments qui augmentent l'intensité et dirigent l'emploi de ces facultés" (Condorcet 2004: 430).

This exerpt from Condorcet illustrates that modern ideas of using advances in technology for the purposes of enhancement, whether it be to enhance physical and cognitive capacities, to enhance moods or to extend human life spans, can be seen as a continuation of the enlightenment project (Hughes 2010) and not as a new proposal of the futuristic transhumanist agenda (Bostrom 1998). Enhancement is not unique to our epoch (Gilbert and Baertschi 2011), and given this observation, one could ask whether the ethics of nanotechnology in general, (Lenk and Biller-Andorno 2007; Alpert 2008; Ferrari and Nordmann 2010) and of nano-bionic device technology in particular, could bring something intrinsically novel to the debate?

What might be perceived as novel is that as the enhancement capacity increases with nano-bionic implants, neuroscience might become less interested in what brains *are*, and more interested in what neuroscience can make brains *become*. This distinction between a pre-enhanced brain (the "given" of what brains are) and what a brain is "made to be" through nano-enhancement implies that the brain can be changed or modified. As nanotechnology becomes more integrated with the brain, the idea arises that a nano implant might change the brain's intrinsic functionality. Supposedly, the kinds of changes available through nano-bionic implants will not be concerned with what brains are being *changed from*, but rather with what brains are being *changed to* – perhaps because of their paradoxical magnitude and subtlety all at once. A potential ethical novelty could result in practicing science in the interests of change rather than preserving brain functionalities (Glover 1984). However, this speculative view has it limits. Indeed, what makes nano-bionic devices any different from other brain enhancers (i.e. pharmaceutical, genetic, electrical, etc.) for making neuroscience more future-oriented than it has been to date? Such an orientation is not exclusive to nanomedicine.

Questioning the intrinsic novelty of nano-bionic devices forces us to ask whether they bring something unique to the relation between a *preoperative* person and a *postoperative* person. In others words, do nano-bionic devices shed any new light on the reasons why a person who is seeking nano-bionic enhancement must be concerned with the postoperative person who she could become? On a first approximation, it appears that at the moment of consent, the person who is seeking nano-bionic cognitive enhancement must care about the post-operative person's life as much as with any other invasive brain intervention. These ethical issues that arise from nano-bionic devices are not categorically distinct from those arising from earlier generations of brain implants. For instance, a person receiving DBS has to pass through a process of consent; this process raises similar ethical issues regarding personality alteration (Gilbert 2012; 2013). In general terms, nano-bionic devices are not unique in that matter. Nano-bionic devices do not seem to intrinsically impose new disproportionate burdens on the postoperative person for the sake of the person consenting to enhance herself. Like other cases of invasive intervention, nano-bionic devices do not exclusively concern the preoperative challenges regarding cognitive enhancement, but rather the potential postoperative issues, such as personality changes, which could occur after the intervention. Although not novel, it needs to be mentioned that this risk of damaging the physical and psychological

integrity of the postoperative person might be morally wrong to ignore; at least the risk ought not to be ignored because of some *laissez faire* policies. Seeking nano-bionic cognitive enhancement requires any patient to be fully informed of the risks involved before, during and after the intervention, but such intervention does not raise any fundamentally new ethical question.

Also, if there is a genuine ethical problem associated with the use of nano-bionic devices for enhancement capacities in healthy subjects, it is not on account of the risks of transformation of personal identity. Indeed, it would be a philosophical blunder to believe that the risks of upsetting personal identity through nano-bionic devices are categorically different from those achieved through pharmacological enhancements (or other forms of enhancers). Concerns that nano-bionic technology may threaten personal integrity are sometimes overstated. Comparatively speaking, a glance at how religion or cultural identity can permanently affect personality tells us that nano-bionic devices may not be more damaging to the integrity of one's person than, say, unconscious social pressure in a healthy individual's life.

To help ensure that the debate concerning the use of nano-brain devices for enhancement is not slowed down by numbers of publications that try in vain to find unique or authentic ethical issues in terms of enhancement, I adopt Nordmann's view that ethical literature should be based on its application rather than on any speculative scenario (Nordmann 2007). I believe that using hypothetical cases to ascertain ethical attitudes toward the risks and benefits of nano-neuro implants for enhancement may lead to social misunderstanding, not to mention social panic (e.g. the impact of somatic nuclear transfer for reproductive purpose[3]). An attempt to involve concrete ethical cases will shape the direction of ethical research toward a rational nanotechnology enhancement debate.

In terms of novelties, it seems that nano-brain devices are not intrinsically unique in terms of enhancement, but I believe they raise a number of issues that need to be considered in future ethical guidelines and clinical trials. Let us look more closely at these issues in the following sections.

## 11.4 Challenge to Informed Consent

As a necessary precondition for informed consent, a healthy individual seeking cognitive enhancement must be (1) a volunteer, chosen without manipulation, undue influence or coercion (2) competent to appreciate the risks and benefits, (3) able to understand alternative treatment options, and (4) free of psychiatric conditions or psychiatric comorbidity. Admitting that the efficacy and safety of nano-bionic

[3]The debate on somatic nuclear transfer for reproductive purpose (reproductive cloning) has been monopolized and depicted without accuracy by the media. This phenomenon has dragged ethical questions on speculative ground and shifted the focus away from issues of safety and efficacy.

devices could be reasonably possible for cognitive enhancement, if a subject lacks one of these four minimum ethical requirements, then the subject should be excluded from invasive neurosurgery.

As an essential element of informed consent – the appreciation of the risks of harm (that subjects must assume) may not be obvious at the time of the decision. Potential patients may be legally competent and free to choose concerning their own physical and psychological integrity, but they may not be able to make meaningfully autonomous decisions regarding consent to nano-bionic cognitive enhancement. When in consultation for cognitive enhancement intervention, a healthy patient may feel invulnerable to safety issues given the possibility of quick beneficial effects. Indeed, healthy populations might underestimate the long-term risk effects of nanomaterials in the pursuit of quick results. A look at the phenomenal increase of the use of botulinum toxin type A or sildenafil, the former for beauty enhancement, the latter for sexual performance, shows that many healthy individuals, with freedom of choice, are not hindered by the potential for long-term risks if there are immediate, tangible benefits (Turner and Sahakian 2006). An incorrect estimation of the risk may result in a notable increase in claims that allege failure to obtain proper informed consent before intervention; this is an issue that plastic surgery is facing (Tebbetts and Tebbetts 2002).

If nano-bionic device clinics for enhancement purposes of healthy subjects become a reality, practitioners have to ensure that a patient's comprehension of the risks and uncertainties is evaluated at the time of obtaining consent. Official national and international guidelines should be developed by multidisciplinary experts. Guidelines could provide information to assist potential patients' decision-making.

Nano-bionic devices for cognitive enhancement purposes could be ethically approved for healthy subjects if subjects make informed decisions and are not coerced. Although not entirely sufficient, this approach to conditions for access to nano-bionic devices will ensure ethical approval for the enhancement field – safety being the core ethical prerequisite. The nano-bionic device enhancement field should avoid being inspired by pure mercantile profit and aggressive marketing; it should avoid the less-than-noble model of the field of plastic surgery, where recently, pathology labeled 'plastic surgery addiction' has been observed (Wright 1986; Phillips et al. 2001). Risk of addiction in relation to enhancement should not be ignored. In terms of nano-bionic implants, the need to continually enhance oneself could lead to risky addiction. Given that a certain level of electric stimulation might result in a certain level of enhancement, who should decide and adjust the implant stimulation level? Famous studies of rat brains using positive reinforcement produced by electrical stimulation have demonstrated addictive, often lethal behavior outcomes (Olds and Milner 1954; Wright 1987). Similar compulsive self-stimulation in human has been already reported in the literature (Portenoy et al. 1986). Postoperative follow-up issues raise many complex questions.

A study by Macoubrie (2005) of public perceptions of nanotechnology found that the public anticipated major benefits from nanotechnology. How do such

perceptions arise in public opinion? Can such opinion influence an individual's informed consent process? Healthy individuals use the media as a primary source of information about new technologies and their possible applications. Although the media have an important role in disseminating information, they also play an influential role in disseminating *mis*information. Can positive media depictions of the potential of nanotechnology for enhancement purposes influence a patient's informed consent? A review of DBS media studies might be able to answer this question. Bell et al. (2010) have reported an insightful study on the impact of enthusiastic media portrayals of DBS on patients' hopes and expectations. They concluded that healthcare providers view media portrayals of DBS as "playing a key role in establishing expectations for DBS patients and for public in general" (Bell et al. 2010). From the point of view of healthy patients who go through an informed consent process because they are willing to enhance their memory, the use of an easily available optimistic depiction (Racine et al. 2007) – both in the medical literature and in the popular media – might be a challenge to truly informed consent. Ford (2009) suggests that the overtly optimistic reports about new neurosurgical innovations generate an "educational vulnerability" for patients. Ford affirms that very often when patients approach neurosurgical techniques, they have already been preconditioned by overly optimistic portrayals of novel brain interventions, and this compromises truly informed consent. Informed consent is an important mechanism for respecting patient autonomy, but in order to reach this ambitious goal, the effect of exposure to unbalanced media reports must be considered.

Based on these observations, enhancement providers would have the responsibility of designing a process for obtaining fully informed consent, while avoiding the exploitation of unrealistic hopes built by optimistic portrayals that do not engage in any ethical examination. Healthy patients seeking enhancement must be educated about the realistic potential of nano-brain devices because they may harbor misconceptions about the potential for enhancement efficacy and underestimate the safety risks.

## 11.5 Recourse to Reasonable Medical Alternatives

The invasive nature of nano-bionic device procedures exacerbates bona fide concerns of safety, as compared to non-invasive pharmacological interventions, such as selective serotonin reuptake inhibitor drugs or beta-receptor blockers. Since pharmacological intake implies less severe risks and adverse complications in both the short and long term, it stands to reason that a non-invasive method is undeniably preferable to surgical interventions for cognitive enhancement.

Although the application of nano-bionic devices does not seem to raise novel ethical problems, significant ethical concerns are nonetheless at stake. Besides the technical difficulties involved in making risk assessments, which try to project the likelihood and extent of harm that could result for healthy patients seeking

nano-bionics enhancement, there are also ethical difficulties to face. These include questions such as:

1. Under what circumstances should healthy individuals have the right to receive nano-bionic devices for cognitive enhancement purposes?
2. What level of prospective benefit could justify such invasive nano-bionic interventions in healthy patients?
3. How should nano-bionic devices be regulated to assure the primary concern for patient safety, without stopping research in this field altogether?

These questions must be thought through and given serious ethical attention before applications for nano-bionic devices can be approved for use in healthy human subjects.

Nano-bionic devices should be seen as a last solution, the appropriateness of which depends on what outcomes a patient wants to achieve through this invasive intervention. Before any invasive intervention could be regarded as an option, it must be proven that it enhances mood as well as functional and cognitive abilities in healthy subjects in general; moreover, it must be proven – with a high level of significance – that it could enhance the very individual asking for the intervention. Any benefit that can result from an individual's enhancement in particular does not necessarily entail that the whole population would be identically enhanced given the same intervention. Not only should it be established that an intervention could enhance the particular individual, but it must also be demonstrated that it is the only alternative left in order to reach that individual's aim. Nano-bionic enhancers must offer an individual significant advantages over non-enhanced individuals; indeed, the level of improvement is often well below the level of normal function (Repantis et al. 2008). Additionally, nano-bionic devices must be proven to be more effective than pharmacological measures available to the individual.

Severe short and long-term side effects have to be eradicated on both a physical and psychological level before nano-bionic devices can be considered a viable option for healthy subjects. Yet, to address the ethics of these requirements, nano-bionic devices must prove themselves, and part of doing so means they must pass scientific muster. At this point, assurances of the safety and efficacy of nano-bionic devices are not borne out in the literature. Current reporting on DBS is particularly vulnerable to researcher/investigator bias because of an excessive reliance on single-patient case reports (Schlaepfer and Fins 2010; Gilbert and Ovadia 2011). Although the risk that selective publishing poses is by no means unique to DBS, it is essential that safety and efficacy be proven, and for this, higher powered studies will be needed. Ethical patient selection for such studies will of course be a challenge. Alternatively, without higher powered studies, investigator bias may drive development of this research.

Rather than imposing a total ban on further nano-bionic implant developments or endorsing total freedom, ethical regulations (informed and uncoerced choice, restriction to cases where there are no other alternatives available, competence to appreciate the risk, no psychiatric conditions or comorbidity) should be evaluated with priority.

## 11.6 Conclusion

There is a wide spectrum of positions in the human enhancement debate. For the advocates of human enhancement, the debate should be solved with respect to a fundamental right: the freedom of choice regarding psychological and physical integrity. What could be wrong with a healthy person enhancing her own brain functions with a nano-device if it harms no one other than perhaps the individual? Following this preliminary investigative chapter, I conclude that regulating enhancement technology for enhancement purposes is not directly infringing on the fundamental right of freedom of choice with regard to physical and psychological integrity. Although there might not be a right to prevent one from deciding to engage in risky interventions that could result in damaging physical and psychological integrity, there is a duty to prevent one from deciding to engage in an unethically invasive intervention that could damage one's physical and psychological integrity. Although nano-bionics for cognitive enhancement is not unethical *per se*, there are sufficient reasons for restricting the kind of interventions surgeons are requested to do. It is a corollary from the necessity to regulate the informed consent that each person's freedom to decide must be limited so as not to directly inflict unnecessary bodily injury on one's own physical and psychological integrity (i.e. the person willing to undergo enhancement), nor on any other (e.g. a surgeon). As seen above, regarding the deliberative informed consent process, it is not clear where the realm of autonomy ends and where the realm of heteronomy begins. Allowing nano-bionic enhancement without the four minimum requirements for a proper informed consent framework is simply unethical. Individual autonomy could not survive without health and safety concerns. If a surgical brain procedure is proven to be safe and effective, the enhancement debate becomes more of a matter for healthcare policymakers rather than an issue based exclusively on the right to freedom of choice.

No one can predict for what purposes bionic devices built with nanomaterials will be used in a few decades or even what nano-bionic devices will become in the history of cognitive enhancement in terms of ethics. Given their current stage of development, nano-bionic technologies for enhancement purposes are more speculative than actual. It would be premature to advocate invasive nano-neurosurgical interventions strictly on the basis of freedom of choice. If one day nano-bionic devices could be used for enhancement purposes, policymakers must ensure that their use will not heighten behavioral consumption patterns and dependency on technology, which are unfortunately related to individuals having freedom of choice.

**Acknowledgement** This research was funded by the Australian Centre of Excellence for Electromaterials Science (ACES). Thanks to Susan Dodds, Eliza Goddard and Timothy Krahn.

## References

Adrian W, Laxton Tang-Wai DF, McAndrews MP et al (2010) A phase I trial of deep brain stimulation of memory circuits in Alzheimer's disease. Ann Neurol 68(4):521–534

Alpert S (2008) Neuroethics and nanoethics: do we risk ethical myopia? Neuroethics 1:55–68

Andrews RJ (2009) Neuromodulation: deep brain stimulation, sensory neuroprostheses, and the neural-electrical interface (In: Sharma HS (ed) Nanoneuroscience and nanoneuropharmacology). Prog Brain Res 180:127–139

Bell E, Maxwell B, McAndrews MP, Sadikot A, Racine E (2010) Hope and patients' expectations in deep brain stimulation: healthcare providers' perspectives and approaches. J Clin Ethics 21:112–124

Berger F, Gevers G, Siep L, Weltring KM (2008) Ethical, legal and social aspects of brain-implants using nano-scale materials and techniques. Nanoethics 2:241–249

Berney A, Vingerhoets F, Perrin A, Guex P, Villemure J-G, Burkhard PR, Benkelfat C, Ghika J (2002) Effect on mood of subthalamic DBS for Parkinson's disease: a consecutive series of 24 patients. Neurology 59:1427–1429

Bostrom N (1998) What is transhumanism? http://www.nickbostrom.com/old/transhumanism.html. Accessed 18 Apr 2012

Bostrom N, Savulescu J (2009) Human enhancement ethics: the state of the debate. In: Savulescu J, Bostrom N (eds) Human enhancement. Oxford University Press, Oxford

Clausen J (2010) Ethical brain stimulation – neuroethics of deep brain stimulation in research and clinical practice. Eur J Neurosci 32:1152–1162

Condorcet N (2004) Tableau historique des progrès de l'esprit humain. Projets, esquisee, fragments et notes (1772–1974). Schandeler J.-P, et Crépel P (eds) Paries: Institut National d'Etudes Démographique

Curiel DT, Agarwal S, Wagner E, Cotton M (1991) Adenovirus enhancement of transferrin-polylysine-mediated gene delivery. Proc Natl Acad Sci USA 88:8850–8854

Daniels N (2000) Normal functioning and the treatment-enhancement distinction. Camb Q Healthc Ethics 9:309–322

Davis J (2009) Peoria's first cochlear implant surgery has grandfather rediscovering life. Peoria Journal Star, 2009-10-29. http://www.pjstar.com/features/x876590686/Peoria-s-first-cochlear-implant-surgery-has-grandfather-rediscovering-life. Accessed 7 Mar 2011

de Condorcet N (1795) Outlines of an historical view of the progress of the human mind [1793]. J. Johnson, London

Drexler EK (1986) Engines of creation: the coming era of nanotechnology. Anchor Books, New York, http://e-drexler.com/d/06/00/EOC/EOC_Table_of_Contents.html

Elliott C (2003) Better than well: American medicine meets the American dream. Norton, New York

Ferrari A, Nordmann A (2010) Beyond conversation: some lessons for nanoethics. Nanoethics 4:171–181

Ford PJ (2009) Vulnerable brains: research ethics and neurosurgical patients. J Law Med Ethics 37:73–83

Franzini A, Marras C, Ferroli P, Bugiani O, Broggi G (2005) Stimulation of the posterior hypothalamus for medically intractable impulsive and violent behavior. Stereotact Funct Neurosurg 83:63–66

Gilbert F (2011) Working while under the influence of performance enhancing drugs: is one "more responsible"? Am J Bioeth Neurosci 2:57–59

Gilbert F (2012) The burden of normality: from 'chronically ill' to 'symptom free'. New ethical challenges for deep brain stimulation postoperative treatment. J Med Ethics. doi:10.1136/medethics-2011-100044

Gilbert F (2013) Deep brain stimulation for treatment resistant depression: postoperative feeling of self-estrangement, suicide attempt and impulsive-aggressive behaviours, Neuroethics. doi: 10.1007/s12152-013-9178-8

Gilbert F, Baertschi B (2011) Neuroenhancement: much ado about nothing? Am J Bioeth Neurosci 2:45–47

Gilbert F, Ovadia D (2011) Deep brain stimulation in the media: over-optimistic media portrayals calls for a new strategy involving journalists and scientifics in the ethical debate. J Integr Neurosci 5:16. doi:10.3389/fnint.2011.00016

Gilbert F, Harris AR, Kapsa RMI (2012) Efficacy testing as primary purpose of phase 1 clinical trials: is it applicable to first-in-human bionics and optogenetics trials? Am J Bioeth Neurosci 3:20–22

Glover J (1984) What sort of people should there be? Penguin, New York

Halliday AJ, Cook MJ (2009) Polymer-based drug delivery devices for neurological disorders. CNS Neurol Disord Drug Targets 8:205–221

Hamani C, McAndrews MP, Cohn M, Oh M, Zumsteg D, Shapiro CM, Wennberg RA, Lozano AM (2008) Memory enhancement induced by hypothalamic/fornix deep brain stimulation. Ann Neurol 63:119–123

Haq I, Foote K, Goodman W, Ricciuti N, Ward H, Sudhyadhom A, Jacobson C, Siddiqui M, Okun M (2010) A case of mania following deep brain stimulation for obsessive compulsive disorder. Stereotact Funct Neurosurg 88:322–328

Harris J (2007) Enhancing evolution. The ethical case for making better people. Princeton University Press, Princeton

Heinze HJ, Heldmann M, Voges J, Hinrichs H, Marco-Pallares J, Hopf JM, Müller UJ, Galazky I, Sturm V, Bogerts B, Münte TF (2009) Counteracting incentive sensitization in severe alcohol dependence using deep brain stimulation of the nucleus accumbens: clinical and basic science aspects. Front Hum Neurosci 3:22

Hochberg L, Serruya M, Friehs G, Mukand J, Saleh M, Caplan A, Branner A, Chen D, Penn R, Donoghue J (2006) Neuronal ensemble control of prosthetic devices by a human with tetraplegia. Nature 442:164–171

Houeto JL, Mesnage V, Mallet L, Pillon B, Gargiulo M, du Moncel ST et al (2002) Behavioural disorders, Parkinson's disease and subthalamic stimulation. J Neurol Neurosurg Psychiatry 72:701–707

Hughes J (2010) Technoprogressive biopolitics and human enhancement. In: Jonathan M, Sam B (eds) Progess in bioethics. MIT Press, Hong Kong, pp 163–188

Juengst ET, Binstock RH, Mehlman M, Post SG, Whitehouse P (2003) Biogerontology, "anti-aging medicine," and the challenges of human enhancement. Hastings Cent Rep 33:21–30

Kennedy PR, Bakay RA (1998) Restoration of neural output from a paralyzed patient by a direct brain connection. Neuroreport 9:1707–1711

Kuhn J, Lenartz D, Huff W, Lee S, Koulousakis A, Klosterkoetter J, Sturm V (2007) Remission of alcohol dependency following deep brain stimulation of the nucleus accumbens: valuable therapeutic implications? J Neurol Neurosurg Psychiatry 78:1152–1153

Lee W, Parpura V (2009) Carbon nanotubes as substrates/scaffolds for neural cell growth (In: Sharma HS (ed) Nanoneuroscience and nanoneuropharmacology). Prog Brain Res 180: 111–125

Lenk C, Biller-Andorno N (2007) Nanomedicine-emerging or re-emerging ethical issues? A discussion of four ethical themes. Med Health Care Philos 10:173–184

Macoubrie J (2005) Informed public perceptions of nanotechnology and trust in Government Woodrow Wilson International Center for Scholars, the Pew charitable Trusts. http://www.wilsoncenter.org/sites/default/files/macoubriereport1.pdf. Accessed 18 Apr 2012

Medtronic (2011) Deep brain stimulation for movement disorders. http://professional.medtronic.com/therapies/deep-brain-stimulation/index.htm. Accessed 7 Mar 2011

NeuroVista (2011) NeuroVista receives approval for expanding Australian clinical study. http://www.neurovista.com/docs/2011-01-30_PressRelease_ApprovalforExpandedTrial.pdf. Accessed 17 Mar 2011

Noda M, Vogel RL, Craig AM, Prahl J, DeLuca HF, Denhardt DT (1990) Identification of a DNA sequence responsible for binding of the 1,25-dihydroxyvitamin D3 receptor and 1,25-dihydroxyvitamin D3 enhancement of mouse secreted phosphoprotein 1 (Spp-1 or osteopontin) gene expression. Proc Natl Acad Sci USA 87:9995–9999

Nordmann A (2007) If and then: a critique of speculative nanoethics. Nanoethics 3:31–46

Olds J, Milner P (1954) Positive reinforcement produced by electrical stimulation of septal area and other regions of rat brain. J Comp Psychol 47:419–427

Partridge BJ, Bell SK, Lucke JC, Yeates S, Hall WD (2011) Smart drugs "as common as coffee": media hype about neuroenhancement. PLoS One 6(11):10.1371/journal.pone.0028416

Phillips KA, Grant J, Siniscalchi J, Albertini RS (2001) Surgical and nonpsychiatric medical treatment of patients with body dysmorphic disorder. Psychosomatics 42:504–510

Portenoy KR, Jarden JO, Sidtis JJ, Lipton RB, Foley KM, Rottenberg DA (1986) Compulsive thalamic self-stimulation: a case with metabolic, electrophysiologic and behavioral correlates. Pain 27:277–290

Racine E, Waldman S, Palour N, Risse D, Illes J (2007) "Currents of hope": neurostimulation techniques in U.S. and U.K. print media. Camb Q Healthc Ethics 16:312–316

Repantis B, Schlattmann P, Laisney O, Heuser I (2008) Antidepressants for neuroenhancement in healthy individuals: a systematic review. Poiesis and Praxis 6:139–174

Schlaepfer TE, Fins J (2010) Deep brain stimulation and the neuroethics of responsible publishing, when one is not enough. JAMA 303:775–776

Snyder DE, Echauz J, Grimes DB, Litt B (2008) The statistics of a practical seizure warning system. J Neural Eng 5:392–401

Synofzik M (2009) Ethically justified, clinically applicable criteria for physician decision-making in psychopharmacological enhancement. Neuroethics 2:89–102

Taniyama Y, Tachibana K, Hiraoka K, Aoki M, Yamamoto S et al (2002) Development of safe and efficient novel nonviral gene transfer using ultrasound: enhancement of transfection efficiency of naked plasmid DNA in skeletal muscle. Gene Ther 6:372–380

Tebbetts JB, Tebbetts TB (2002) An approach that integrates patient education and informed consent in breast augmentation. Plast Reconstr Surg 110:971–978

Tsai HC, Chen SY, Tsai ST, Hung HY, Chang CH (2010) Hypomania following bilateral ventral capsule stimulation in a patient with refractory obsessive-compulsive disorder. Biol Psychiatry 68:7–8

Turner DC, Sahakian BJ (2006) Neuroethics of cognitive enhancement. Biosocieties 1:113–123

Wilz A, Pritchard EM, Li T, Lan JQ, Kaplan DL, Boison D (2008) Silk polymer-based adenosine release: therapeutic potential for epilepsy. Biomaterials 29:3609–3616

World Health Organization (1946) Preamble to the constitution of the World Health Organization as adopted by the International Health Conference. http://www.who.int/about/definition/en/print.html. Accessed 18 Apr 2012

Wright MR (1986) Surgical addiction: a complication of modern surgery? Arch Otolaryngol 112:870–872

Wright HN (1987) Characterization of olfactory dysfunction. Arch Otolaryngol 112:870–872