D3.1: State-of-the-art Review

[WP3 – Human Enhancement]

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Abstract

This report describes the current state-of-the-art in the field of human enhancement. We establish the definition and demarcations for human enhancement that will be used in subsequent SIENNA research on human enhancement, as well as discuss the field in terms of background, positions, and challenges. The report also includes a review of present and expected applications as well as a socio-economic impact assessment. Our conclusion summarises our findings and offers recommendations for how we will proceed with subsequent SIENNA work on human enhancement.

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Linked task	Points of relevance
Task 2.1	Gene-editing technologies for human enhancement
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Task 3.3	Report definitions may help to identify consistencies or differences from existing REC approaches & codes
Task 3.4	SEIA & review of applications may inform ethics inquiries
Task 4.1	AI & robotics technologies for human enhancement

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Executive summary

The introductory chapter establishes the goals for this state-of-the-art review; namely, defining how SIENNA views human enhancement technology (HET). We provide a brief background on the field, then explain the objectives and structure of the report. The introduction also identifies important challenges and limitations to the report.

The definitions & demarcations chapter documents in greater detail SIENNA's starting point on HET. We provide additional background information about the field, including a brief review of existing definitions for HET. In this chapter, we define human enhancement as '*A modification aimed at improving human performance and brought about by science-based and/or technology-based interventions in or on the human body,'* which is adapted from a similar definition established by the European Parliament.[1] We explain why we develop this definition in favour of others.

In addition, we identify demarcations including subfields, important concepts and positions on HET, including categorising HETs by target in one of six categories: cognitive, affective, moral, physical, cosmetic or longevity. We also introduce alternative categorisations for HET based on delivery methods (i.e., biomedical, machine-based or genomics) or domain (i.e., healthcare, education, workplace, military/defence and home or recreation). In this chapter, we also address scientific & technological challenges and expected developments in the field.

The existing & expected applications chapter reviews the most important HET applications that exist or are expected within the next twenty years following our initial literature review. We provide a timeline of expected application developments, discuss existing & expected applications by technique (biomedical, machine-based or genomics) then review 26 applications categorised by domain (healthcare, education, workplace, military/defence and home or recreation).

The SEIA chapter documents the approach for and findings of the socio-economic impact assessment (SEIA) for HETs. We define SEIA as a systematic analysis used to identify and assess the socio-economic impacts of HETs on society. The objective of this SEIA was to identify and assess current and expected social, economic and environmental impacts of HET. Impacts refer to the potential changes caused – directly or indirectly, in whole or in part, for better or for worse – by the technologies under consideration. The chapter focuses on social impacts (those related to society in general, specific groups, and the individual, such as human health, abilities social inequalities), economic impacts (those associated with economic effects on the individual, groups and society in general, such as unemployment, economic inequalities and costs), and environmental impacts (those related to the natural environment, such as those that degrade the environment, deplete or increase natural resources and affect the climate).

Although not all impacts and their assessments will be summarised here in this executive summary, the SEIA identified some social impacts that might have either a positive or negative impact or both. Regarding the economic impacts, HETs present opportunities to increase community wealth, promote economic growth and business opportunities via further development in the healthcare sector. The environmental impacts could be either positive or negative depending on their specific application. A big concern here is that HETs might contribute to some environmental degradation through the

[1] Coenen, Christopher, et al, *Human Enhancement*, EU Parliament, STOA, May 2009. https://www.itas.kit.edu/downloads/etag_coua09a.pdf

generation of greater technological waste. This does not mean that HETs may represent a greater threat than any other technologies though it could exacerbate the problem.

According to the mini survey data, impacts of *high significance* include: increase in reliance on technology; change in the perception of what makes us human; effects on the freedom of individuals; change in the freedom of choice and cultures of individuals with disabilities; creation and/or increase in social inequalities; burden on economic resources due to increasing human lifespans and abilities; and perpetuation and/or increase in economic inequalities. Impacts with *high to medium* significance include social disruption and negative impacts on vulnerable populations and adverse impact on developing and least-developed nations. Harm to human health can be viewed as a *medium* significance impact. Impacts of *low* significance include adverse impacts on international trade relations and adverse impact on the environment (e.g., creation of technological waste, toxicity).

The **timing of the impacts** will follow and depend on timelines for HET adoption and implementation. These will vary across regions and countries.

Based on our research, we find that the **societal values that are and will be most under threat** from HETs include: autonomy, dignity, equality, fairness, health and safety, peace, privacy, respect for human life and solidarity. As shown in our report, resilience will be conditional on the presence of certain factors. Given our research so far and the state of the art in HETs, the **most vulnerable communities** will be patients, disabled, elderly and children (e.g., due to lack of choice and decision-making power in use of HET coupled with lack of understanding of full implications). The impacts of HETs on such groups should be carefully monitored (and if necessary regulated).

One of the impacts identified in this exercise that we see pointing to unmanageable change relate to the **changing nature of the 'human'** or what we have previously come to know and acknowledge as 'human'. Other impacts are of a more generic nature, widely applicable not just to HETs and for which societies have coping and change management mechanisms. HETs have the 'potential to provide many benefits to both individuals and society provided that it is fairly distributed',[2] but we also need to consider the costs of their impacts. Some of these costs could be direct (attributable to the technology itself) or indirect (not attributable to the technology but connected to the broader impact is has on society). Some costs may be avoidable by virtue of being fixed in the long run or unavoidable due to their variability in the short run.

A range of measures are available and can be leveraged to mitigate any adverse impacts of HETs. These include **policy and regulatory measures** *(responsibility: policy-makers, regulators, national ethics committees),* **technological/industry measures** *(responsibility: companies, industry associations, HET designers and innovators),* ***society-level measures*** (*responsibility:* academia, civil society, media) and **individual-level measures** *(responsibility: individuals using HETs, considering their use, affected by such HETs)* (see section 4). Many of the mitigation measures seem to be directed at the policy or regulation level. None of these are novel per se and are constantly used in different technological domains to varying effects and degrees to mitigate adverse consequences and with different levels of success.

Based on its results, the SEIA makes some recommendations to address the negative impacts and boost the positive impacts of HETs.

Our conclusion summarizes the findings of our research for the state-of-the-art review on HET. In particular, we note the 'emerging' status of the field, pointing out that although it is currently difficult

[2] Swindells, Fox, "Economic Inequality and Human Enhancement Technology", *Humana Mente Journal of Philosophical Studies*, 2014, Vol. 26, 213-222. http://www.humanamente.eu/PDF/Issue26_Paper_Swindells.pdf

to find researchers who self-describe themselves as working on the development of HET, we expect this will begin to change over the next ten years. In addition, we sketch out what we shall attempt to accomplish in the remaining SIENNA work on HET, i.e., subsequent reports on ethical, legal and human rights issues as well as research on social perceptions on technologies in the field. Finally, we deliver the most meaningful findings from our SEIA with short and long-term recommendations for future studies.

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List of acronyms/abbreviations

Abbreviation	Explanation
3D	Three-dimensional
ADHD	Attention deficit hyperactive disorder
AI	Artificial intelligence
AR	Augmented reality
BCI	Brain-computer interface
CES	Cranial electrotherapy stimulation
DARPA	Defense Advanced Research Projects Agency (US)
DBS	Deep brain stimulation
DIY	Do-It-Yourself
EEG	Electroencephalograph (or electroencephalography)
FGCS	Female genital cosmetic surgery
HET	Human enhancement technology
HGH	Human growth hormone
iEEG	Intracranial electroencephalography
INI	Implanted neural interface
IPA	Intelligent personal assistant
IPED	Image & performance-enhancing drug(s)

Abbreviation	Explanation
IVF	In-vitro fertilization
PCE	Psychopharmaceutical cognitive enhancement
PGD	Preimplantation genetic diagnosis
RFID	Radio-frequency identification (or identity)
rTMS	Repetitive transcranial magnetic stimulation
SEIA	Socio-economic impact assessment
STOA	Science and technology options assessment
SSRI	Selective serotonin reuptake inhibitor
tDCS	Transcranial direct-current stimulation
TENS	Transcutaneous electrical nerve stimulation
TMS	Transcranial magnetic stimulation
TTS	Text-to-speech
VR	Virtual reality
WP	Work package

Table 1: List of acronyms/abbreviations

Glossary of terms

Term	Explanation
High-tech enhancement	Human enhancement resulting from science and/or technology-based practices or interventions; one example is using neural stimulation techniques to improve cognition
Human enhancement / human enhancement technology	A modification aimed at improving human performance and brought about by science-based and/or technology-based interventions in or on the human body
Intervention	Any type of procedure, use of application or technique to achieve a result
Low-tech enhancement	Human enhancement resulting from common practices or interventions; one example is participating in public education. In SIENNA, we will not pursue conclusions about low-tech enhancement
Medicalization	The practice of companies lobbying to convince the public that a circumstance previously not treated as a medical disability requires treatment
Non-therapeutic enhancement	Interventions with no therapeutic benefit that result in enhancement
Off-label use	Use of a therapeutic intervention for enhancement without scientific or medical direction
Restorative, preventative non-enhancing	Interventions (often medical) that result merely in a return to baseline health/performance standards
Science-based	Based on knowledge or a process developed from scientific research
Technology-based	Based on the utilisation or integration with a technological artefact
Therapeutic enhancement	Interventions that are often performed to return an individual's health/performance to their baseline but may also increase health/performance beyond the baseline

Table 2: Glossary of terms

1. Introduction

The primary goal of SIENNA Work-package Three (WP3) is to conduct research that will lead to an ethical, legal and regulatory framework for the use and development of human enhancement technologies. We begin in this report, SIENNA D3.1, with a state-of-the-art review of the field based on a literature review and a study of its socio-economic impacts (based on both a literature review and a limited stakeholder survey).

Human enhancement technologies (HETs), broadly speaking, include applications and interventions that permanently or temporarily improve human capabilities. Existing HETs include neural stimulation techniques like transcranial direct-current stimulation (TDCS), which can improve cognitive performance, image & performance-enhancing drugs (IPEDs) and cosmetic surgery. In the near future, we anticipate the arrival of HETs that will allow users to better control their affective state, that implants and advanced prosthetics will increase human performance in a variety of ways, and that safer IPEDs requiring less regulation will become available. HET is sometimes associated with biohacking or human augmentation, although these terms may also be used to refer to other technologies. It can be difficult to assess the field of human enhancement because the range of applications and interventions that count as HETs will vary based on the definition used. Furthermore, even after settling on a definition there is a major challenge in identifying experts because the field remains poorly defined, especially with regards to empirical research. In chapter 2, we will offer our preliminary definition and explain why we have chosen it from many existing definitions that have been proposed in the literature.

1.1 Background

On the broadest definitions, human enhancement is nothing new. At least since humans began organising into societies, we have sought to improve ourselves. Agricultural advances have improved nutrition, which has increased longevity. The development and standardisation of education has increased norms for intelligence. Perhaps most of all, scientific pursuits have led to a multitude of discoveries and inventions that could, on some definitions, be considered human enhancement, especially with regards to medicine. Today, many widely-accepted activities are known to have enhancing effects, such as drinking caffeinated beverages like coffee.[3]

Enhancement via high-tech intervention dates back, at least, to World War II. On both sides, soldiers received amphetamines (Pervitin or Benzedrine) to keep them in fighting shape during long campaigns.[4] Following the war, there is evidence that suggests Benzedrine was also used as a creativity enhancer by writers and became popular as a cognitive enhancer in some areas, such as Rio de Janeiro, although the use of these amphetamines in the 1940s and 50s as enhancement drugs does not appear to have given rise to the philosophical debate on HET.[5]

[3] Maslen, Hannah, Nadira Faulmüler, and Julian Savulescu, “Pharmacological cognitive enhancement--How neuroscientific research could advance ethical debate,” *Frontiers in Systems Neuroscience* Vol. 8, November 2014.
[4] Ohler, Norman, *Blitzed: Drugs in the Third Reich*, Mariner Books, 2018..
[5] Currey, Mason, “The Secret to Ayn Rand's Success: Benzedrine,” *Slate Magazine*, April 22, 2013. http://www.slate.com/articles/arts/culturebox/features/2013/daily_rituals/auden_sartre_graham_greene_ayn_rand_they_loved_amphetamines.html; Marcelo de, Araujo, “Pervitin Instead of Coffee? Change in Attitudes to Cognitive Enhancement in the 50’s and 60’s in Brazil,” *Practical Ethics News*, September 9, 2015. http://blog.practicalethics.ox.ac.uk/2015/09/guest-post-pervitin-instead-of-coffee-change-in-attitudes-to-cognitive-enhancement-in-the-50s-and-60s-in-brazil/.

The modern moral debate on HETs arose in the mid-20th century alongside the development of early biotechnology and research on genetic engineering. Half a century later, many of the fears that arose in the early period have failed to come to pass, such as the commodification of gene editing on human embryos. However, as the development of technology has accelerated over the last several decades, two extreme positions have emerged: transhumanism, which promotes widespread use and development of HETs and is supported by Bostrom and Sandberg (among others)[6], and bioconservatism, which strongly objects to virtually all use and development of HETs, depending on the definition, and is supported by Kass and Sandel (among others).[7] Less-extreme views may support some forms of enhancement but draw a line that should not be crossed, for example on using pharmaceutical enhancements on children. We will attempt to consider all sides of the argument, including other perspectives, as we proceed in WP3.

The history of the field of HETs is more difficult to trace than those in SIENNA WP2 on genomics or SIENNA WP4 on AI & robotics because research on HET, especially empirical and clinical research, is still emerging. Previously, human enhancement has existed as more of an application area than a true, well-defined technological field. Research on enhancing effects in therapeutic treatment was rarely performed until the previous decade. Advances in biomedicine, computer technologies and other fields are turning what used to be considered science-fiction into true possibility.

1.2 Objectives

Because the field of HET remains poorly defined, one of our primary objectives in this report is to propose definitions and demarcations that will guide our inquiries in our future work. We will also provide a basic review of existing and expected applications. To begin, expected applications in HET may appear in one of six categories of enhancements: *cognitive, affective, moral, physical, cosmetic*, or *longevity*. Each categorical label is meant to be straightforward. *Cognitive enhancements* are interventions that improve cognitive abilities. *Affective enhancements* are interventions that improve and/or provide greater control over a human's affect. *Moral enhancements* are interventions that modulate or otherwise positively alter a human's moral disposition, whether via changing their actions or otherwise. *Physical enhancements* are interventions that improve or introduce new physical abilities. *Cosmetic enhancements* are interventions that improve the cosmetic traits of a human being. Finally, *longevity enhancements* are interventions that extend a human's lifespan. These categories, along with additional discussion about the expected delivery methods and locations for HET, will be discussed further in chapter 2.

There are many potential social impacts HETs may deliver in the near future—both positive and negative. For example, if the use of HETs becomes widespread in a society, the result could be a lateral increase of standard, or baseline, human ability in that society. Attempts to maintain or continue improving the new baseline could result in an increased reliance on technology in such a society, which may exacerbate risks due to the possibility of technological glitches or failures. Furthermore, individuals may use enhancements to gain a competitive advantage, or edge, over non-enhanced competitors in many settings, such as the workplace, education or professional sports. Individuals may

[6] Bostrom, Nick, "In Defense Of Posthuman Dignity," *Bioethics* Vol. 19, No. 3, 2005, pp. 202–214; Sandberg, Anders, "Cognition Enhancement," *Enhancing Human Capacities*, 2014, pp. 69–91.
[7] Kass, Leon, *Life, Liberty and the Defense of Dignity: The Challenge for Bioethics*, Encounter Books, San Francisco, 2004; Sandel, Michael J., *The Case against Perfection: Ethics in the Age of Genetic Engineering*, Belknap Press of Harvard University Press, Cambridge, MA, 2007.

also choose to use HETs recreationally or for purposes other than improving one's capabilities. These and additional impacts will be further assessed in chapter 4.

1.3 Structure of the report

In the following pages, this state-of-the-art review will serve as the SIENNA project's preliminary assessment of the field of HETs. In chapter 2, we will define the field of HETs, which will include a demarcation and definition of human enhancement, explanation of core ideas, description of subfields and discussion of present and future challenges. In chapter 3, we will deliver a systematic description of products and applications that have been developed or are expected to soon be developed within the field. In chapter 4, we will deliver a socio-economic impact assessment on HETs. Finally, in chapter 5, we will conclude with a summary and recommendations for further study.

1.4 Scope and limitations

This report precedes further SIENNA work on ethical, legal and social aspects of human enhancement. As such, we do not plan to deliver conclusions on these issues in this document. In order to develop the most useful guidelines for the field, it is necessary to resist focusing too heavily on visionary speculations; for example, an enhancement to completely stop the aging process. We will attempt to keep our focus on developments that are plausible within the next twenty years, and especially what is likely to develop in the next five to ten years. Chapter 3 of this document consists of a review of many applications that are already available or expected within this timeframe.

Due to the difficulty in identifying experts in the field, this report consists of research emerging almost exclusively from literature review. Further work in WP3 will include stakeholder input via interviews and surveys.

2. Defining the field

The moral debate on HET is not new. Many ethicists, philosophers and scientists have proposed a variety of definitions for human enhancement over the last several decades. The one constant is captured by the term itself: human enhancements *enhance humans*. The trick is then to settle on a more meaningful definition that correctly captures the technologies the author, or in this case the SIENNA consortium, has in mind.

If all it takes for something to count as HET is for it to enhance human capability, then most humans use HET every day. One could claim that clothing enhances our capability to cope with a wide range of different environments, reading a newspaper enhances our intelligence with regards to our knowledge of current events or eating a healthy breakfast enhances our ability to navigate a busy day by ensuring one's body is well-nourished. However, when considering HET, few stakeholders are interested in everyday 'enhancements' such as these. Where do we draw the line?

2.1 Definition

In 2009, the European Parliament published a detailed report on HET. They used the following definition: 'We define "human enhancement" as a modification aimed at improving individual human performance and brought about by science-based or technology-based interventions in the human body'.[8] Based on this definition, the previous everyday examples of 'enhancements' fall short. Clothing is, at least, not a modification within the body, and reading a newspaper or practicing good nutrition[9] are neither science-based nor technology-based interventions. On the other hand, using methylphenidate to increase focus[10] fits the definition perfectly: it is a modification aimed at improving an individual's cognitive performance brought about by a science-based intervention in the human body.

The European Parliament's definition successfully designates most of what we want to think of as HET, and successfully designates many everyday 'enhancements' as something else. However, the definition restricts HETs to *individual* human performance and interventions that directly affect a human body. As several technological fields converge, we wish to observe the possibility for HETs to alter or improve the entire human species' capabilities, as well as the possibility for an external technology to count as HET, such as a wearable accessory that can be easily removed yet clearly enhances capabilities when worn.

With these observations in mind, we propose the following definition: **'human enhancement' is a modification aimed at improving human performance and brought about by science-based and/or technology-based interventions in or on the human body.** We believe the slight changes we have made to the European Parliament's definition will help to expand our research enough to include important upcoming technologies without expanding it so far as to classify weaker 'enhancements' alongside our research targets.[11]

Many other notable definitions can be found in the literature. However, alternative definitions tend to raise issues that would make it difficult to achieve SIENNA's objectives. For instance, Savulescu has proposed a 'welfarist' definition meant to solve hard cases often proposed in the debate.[12] Cabrera

[8] Coenen, et. al., op. cit., 2009.
[9] One could argue that nutrition, today, constitutes a field of knowledge in its own right, such that one's capacity to 'practice good nutrition' relies on some level of scientific knowledge. In addition, most of the food humans consume today is processed and preserved via means consistent with 'technology-based interventions.' However, it doesn't seem quite right to position 'food technologies' as HET alongside implanted neural interfaces or psychopharmaceutical cognitive enhancers, perhaps due to the so-called 'Flynn effect', or the iodization of cooking salt in many regions of the world throughout the 21st century. This effect is believed to explain, at least in part, the massive increase in IQ throughout the past century; see Steen, R. Grant. 2009. *Human intelligence and medical illness: Assessing the Flynn effect*. New York: Springer, p. 83-84.
[10] Linssen, A. M. W., E. F. P. M. Vuurman, A. Sambeth, and W. J. Riedel, "Methylphenidate produces selective enhancement of declarative memory consolidation in healthy volunteers," *Psychopharmacology* Vol. 221, No. 4, 2011, pp. 611–619.
[11] Depending on the direction in which the field of HET develops, our definition may require revision if, for example, substantial technologies are made available that enhance human beings without requiring an individual human to directly interact with them, i.e., a robust AI-based system specifically created to enhance humans who are not presently interacting with the system. However, at present we believe specifying that HET requires an intervention to occur in or on a human body successfully expands the scope of the field beyond the 2009 European Parliament definition without making it so broad as to include, for example, simple computational technologies such as a number of 'smart home' lights, thermostats and other devices which may, in some ways, enhance productivity but either never or only rarely intervene within or on a human body. That said, daily interactions with software, i.e., with an intelligent personal assistant (IPA), may still fit our definition depending on factors such as the scope of the interactions and whether or not changes occur within an individual's body due to those interactions.
[12] Savulescu, Julian., "Justice, Fairness, and Enhancement," *Annals of the New York Academy of Sciences* Vol. 1093, No. 1, January 2006, pp. 321–338.

has proposed a milder definition than Savluescu, but it still references 'well-being'.[13] If we were to adopt the definition of either author, we would also need to define and demarcate what we mean by 'welfare' or 'well-being', which is not among SIENNA's objectives.

Another notable definition was first proposed by Daniels.[14] His definition, like many others' who have weighed in on the debate, is meant to solve tricky cases, in this instance by referring to the 'normal functioning' of human ability.[15] However, defining what counts as 'normal functioning' is not as straightforward as it may seem[16], and, once again, is not among SIENNA's objectives. Although many of the alternative definitions in the literature may help to illuminate some important issues in the debate, we have chosen the definition above for the pragmatic purpose of most effectively staking out the HETs that exist or are most likely to be developed within the next twenty years in order to produce a functional ethical framework to guide the responsible development of such technologies.

Our definition includes the terms 'science-based', 'technology-based' and 'interventions'. An intervention can be the use of pharmaceutical applications, such as a pill or injection, a surgery or similar professional procedure, integration with a prosthetic device or wearable or integrating the use of novel software for a technological device into one's life. Distinguishing between science versus technology-based interventions will most often mean separating biomedical procedures from the integration with discrete technological items, though the distinction is not always clear-cut; therefore, we say 'science-based *and/*or technology-based'. However, it is important to note that keeping our focus on science and technology-based interventions is meant to keep other interventions, such as via a public education system, from counting as HET unless they are also science and/or technology-based.

2.2 Demarcations

Three major demarcations for HETs tend to appear in the debate: treatment versus enhancement, normal versus better-than-normal, and natural versus artificial. Each demarcation helps to distinguish important features of HET. Unfortunately, each demarcation also has some weaknesses; presently, no perfect demarcation has been proposed.

Both the normal versus better-than-normal and natural versus artificial demarcations appear highly intuitive. In the former case, any intervention that can improve someone's 'normal' abilities above what is considered normal for the entire species is an enhancement. However, discussing what is 'normal' versus what is 'better-than-normal' implies there will also be states that are 'abnormal' or 'worse-than-normal'. Nussbaum has extensively argued against views that presuppose disability implies lesser value[17], demonstrating that it's not so clear where one should draw the line regarding

[13] Cabrera, Laura, and John Weckert, "Human Enhancement and Communication: On Meaning and Shared Understanding," *Science and Engineering Ethics* Vol. 19, No. 3, May 2012, pp. 1039–1056.
[14] Daniels, Norman, "Normal Functioning and the Treatment-Enhancement Distinction," *Cambridge Quarterly of Healthcare Ethics* Vol. 9, No. 03, 2000.
[15] Ibid.
[16] For instance, there can be a wide range of ability with regards to stamina, endurance, perception, etc. Furthermore, deciding that, for example, colour-blindness constitutes 'less-than-normal' functioning may raise issues from colour-blind persons who perform at the same level or better than persons who are not colour-blind, just to name a few reasons to avoid Daniels' account.
[17] Nussbaum, Martha Craven, *Creating capabilities: the human development approach*, The Belknap Press of Harvard University Press, Cambridge, MA, 2013.

'normality'. Nussbaum's argument has been extended to discuss human enhancement by Coeckelbergh.[18]

In the latter case, that is, the natural vs artificial demarcation, any intervention that doesn't naturally occur and results in the enhancement of capabilities is an enhancement. However, many arguments exist that show serious difficulties in separating the so-called artificial from the so-called natural. Unless one utilizes a clear-cut heuristic, which is likely to lead to other problems like arbitrariness, differentiating natural and artificial interventions could introduce a sorites paradox: for example, if a group of scientists discover that ingesting a combination of naturally-occurring reagents results in enhancement after conducting an experiment, is it natural because of the status of the reagents or artificial because the discovery occurred from the result of scientific investigation? There are many biomedical (i.e., technology and/or science-based) interventions that rely on natural methods; are such interventions natural or artificial? In order to avoid these issues, we will proceed by utilizing the remaining demarcation: treatment versus enhancement.

Demarcating HETs based on whether an intervention is a treatment or enhancement can occasionally result in conclusions that seem arbitrary. For instance, there may be a case in which one person is eligible for a treatment while another is ineligible for an enhancement despite the results demonstrating nearly identical ends. This type of case has been discussed regarding the use of human growth hormone (HGH) as a treatment for children with HGH deficiency or an enhancement for children shorter than average who have no HGH deficiency.[19] However, there are pragmatic reasons to accept the treatment versus enhancement distinction for HET, as it can be a straightforward way to make policy decisions. If an intervention is meant to return an individual's capabilities back to what they were before suffering some malady, then it is a treatment. If an intervention is meant to increase an individual's capabilities beyond what they have previously been, especially if the individual is not suffering from a malady, then it is an enhancement. Because SIENNA's goal is to provide a useful ethical framework for HETs, we will proceed with the treatment versus enhancement distinction. If we find or invent a more useful distinction as the project moves forward, we may adopt this different distinction for future work in WP3.

Demarcation	Explanation	Issue
Normal vs better-than-normal	Interventions that improve capabilities above the normal baseline are enhancements	Implies there will be 'abnormal' or 'worse-than-normal'
Natural vs artificial	Any intervention without a natural biological basis that improves capabilities is an enhancement	Requires problematic heuristic that leads to arbitrariness
Treatment vs enhancement	Interventions that do more than treat an individual's reduced capabilities are enhancements	May result in some seemingly arbitrary conclusions

Table 3: Common demarcations for HET

[18] Coeckelbergh, Mark, "Human development or human enhancement? A methodological reflection on capabilities and the evaluation of information technologies," *Ethics and Information Technology* Vol. 13, No. 2, June 2010, pp. 81–92.

[19] Murray, Thomas H., "Research on Children and the Scope of Responsible Parenthood", in Bonnie Steinbock, Alex John London and John D. Arras (eds.), *Ethical Issues in Modern Medicine: Contemporary Issues in Bioethics,* 6th ed. Boston, MA, 2002, 791-805.

Another useful demarcation was advanced in the same European Parliament document from which we have adopted our definition of HET. The authors noted three categories of interventions: 'restorative, preventative non-enhancing', 'therapeutic enhancement', and 'non-therapeutic enhancement'.[20] These categories can serve to help further distinguish the status of individual interventions. Restorative, preventative non-enhancing interventions encompass most traditional 'treatments' and common healthcare procedures. Such interventions have no known enhancement potential for healthy persons. Therapeutic enhancements are most commonly used to return a diminished capability back to an individual's previous baseline but may also be used to improve capabilities further than one's starting baseline. Non-therapeutic enhancements are used only for enhancement purposes with no compelling therapeutic potential. For our purposes in the SIENNA project, these demarcations are most useful for establishing clear-cut cases of HET, i.e., when an application fits the non-therapeutic enhancement category. These demarcations may also help to demonstrate how some applications may evade clear-cut categorization if they fit the therapeutic enhancement category. It has been pointed out that it may be possible for the same intervention to fit both the therapeutic enhancement and non-therapeutic enhancement categories depending on its use-case. For example, when modafinil is prescribed for the treatment of narcolepsy it appears to be a therapeutic enhancement. However, when students use modafinil off-label for the sheer purpose of cognitive enhancement the same intervention appears to be a non-therapeutic enhancement. For our purposes, modafinil should be considered a therapeutic enhancement because even though the student is using the drug for sheer enhancement the drug itself remains the same, meaning it maintains its capacity to treat narcolepsy regardless of how it may be used for different (enhancement) purposes. For an HET to be non-therapeutic, there must be *zero* compelling therapeutic potential for the intervention, regardless of the possibility of the intervention having multiple use-cases. In practice, this requirement raises a high bar for non-therapeutic enhancements, which seems right: it's likely that ethical (or other) issues will sometimes differ for therapeutic and non-therapeutic enhancements.

Demarcation	Explanation	Example
Restorative, preventative non-enhancing	Intervention that have no known enhancement potential for healthy persons	Most traditional treatments and healthcare procedures, i.e. antibiotics, surgery, physical therapy
Therapeutic enhancement	Intervention commonly used to return diminished capability back to previous baseline, but may also improve capability beyond the initial baseline	Existing psychopharmaceutical cognitive enhancements (PCEs), i.e. methylphenidate or some beta-blockers, drugs like Viagra, LASIK surgery, and Tommy John surgery
Non-therapeutic enhancement	Intervention with no compelling therapeutic potential, just enhancement	Speculative intervention that grants the ability to see clearly in the dark, 'designer baby' engineering

Table 4: European Parliament demarcations for HET

A final way to distinguish HET is by separating low-tech and high-tech enhancement. Low-tech enhancements are methods that improve human capability without scientific or technological intervention. Examples of low-tech enhancement include public education, playing a musical instrument, practicing good nutrition[21] and dancing. High-tech enhancements utilize scientific and/or technological interventions, as defined above. In SIENNA, we will not pursue conclusions about low-tech enhancements; in fact, we arrived at our definition for HET above partially in consideration of how to avoid the inclusion of low-tech enhancements in our research. This is because including low-

[20] Coenen, et. al., op. cit., 2009.
[21] Please refer to Footnote 9 above regarding whether or not nutrition is an HET.

tech enhancements is likely to create additional challenges, as individuals may have moral intuitions that hold for high-tech enhancements but not for low-tech enhancements. The benefits of many interventions that would count as low-tech enhancement are well-known and non-controversial, whereas many of the moral norms for high-tech enhancements have yet to be developed.

2.3 Positions on enhancement

In the introduction, we mentioned the extreme positions on HET of transhumanism and bioconservativism. Transhumanists advocate the acceleration of research and development of HETs often stemming from the belief that such technologies will lead to meaningful improvements for society. Notable transhumanists include Bostrom,[22] Kurzweil,[23] Savulescu[24] and Harris.[25] On the opposite side of the spectrum, bioconservatists advocate extreme caution regarding the development of HET, often arguing that HET will prove to be harmful for society for a variety of reasons. Notable bioconservatives include Kass,[26] Fukuyama,[27] Annas[28] and McKibben.[29]

Many other positions exist between the extremes. For example, some hold an ad-hoc position advocating for the development of HETs or caution against it on a case-by-case basis.[30] This position can apply to categories of enhancements, like advocating for cognitive enhancements but not physical enhancements, or be more granular, by considering each individual intervention by itself. Others take a moderate view, arguing that enhancement up to a certain point may be desirable, but it is undesirable to surpass this point, whatever it is. One example of this kind of view is drawing a line regarding cognitive enhancements for children due to numerous social and neurodevelopmental issues.[31]

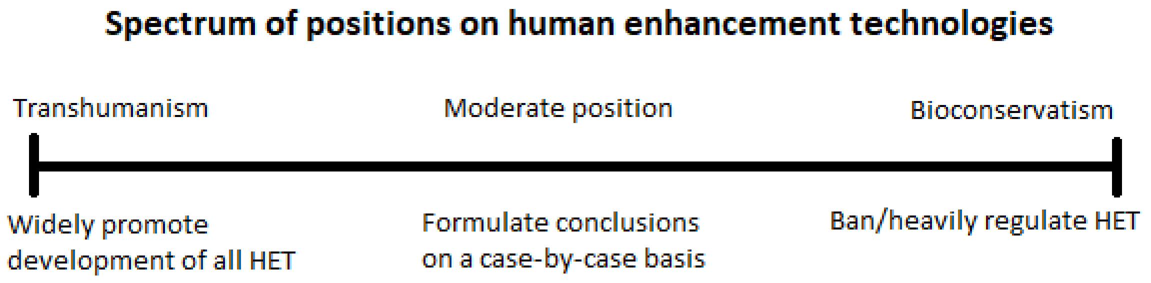

Figure 1: Spectrum of positions on HETs

[22] Bostrom, op. cit. 2005.
[23] Kurzweil, Ray, "The Singularity is Near," *Ethics and Emerging Technologies*, 2014, pp. 393–406.
[24] Savulescu, op. cit. 2006.
[25] Harris, John, *Enhancing Evolution: The Ethical Case for Making Better People*, Princeton University Press, Princeton, NJ, 2010.
[26] Kass, op. cit. 2004.
[27] Fukuyama, Francis, "Transhumanism," *Foreign Policy*, No. 144, 2004, p. 42.
[28] Annas, George J, "The Man on the Moon, Immortality, and Other Millenial Myths: The Prospects and Perils of Human Genetic Engineering, " *Emory Law Journal* Vol. 49, No. 3, Summer 2000, 753-782.
[29] McKibben, Bill, *Enough: Staying Human in an Engineered Age*, Owl Books edition, New York, 2004.
[30] Mukerji, Nikil, and Julian Nida-Rümelin, "Towards a Moderate Stance on Human Enhancement," *Humana.Mente Journal of Philosophical Studies* Vol. 26, 2014, pp. 17–33.
[31] Graf, William D., Saskia K. Nagel, Leon G. Epstein, Geoffrey Miller, Ruth Nass, and Dan Larriviere, "Pediatric neuroenhancement: Ethical, legal, social, and neurodevelopmental implications," *Neurology* Vol. 81, No. 17, 2013, pp. 1558–1559.

2.4 Additional clarifications

HET classified as therapeutic enhancement may be used by healthy individuals for enhancement purposes. Often, this kind of usage constitutes 'off-label' use, because few such interventions have been approved by regulatory agencies for enhancement use. 'Off-label' use denotes when an intervention is applied without direction from a medical or scientific expert. Several HETs were developed as treatments then later found to also have some level of enhancing effects for healthy individuals. Examples include psychopharmaceutical cognitive enhancements (PCEs), such as methylphenidate and modafinil, which have been found to have limited cognitive enhancement potential.[32] Currently, few standards are in place for the research and development of non-therapeutic enhancements, making observed off-label effects a promising research objective, if only to better understand the potential for negative side-effects in healthy subjects who may be tempted to undergo off-label use for enhancement purposes. In fact, precisely this position has been advocated by Lev et. al., authors of an influential document on human subjects' research.[33] Challenges regarding off-label use may be less worrisome in the EU than in North America due to different regulations regarding advertisements for medical interventions.

HET is an emerging field of technology. Although research is thriving in certain areas, such as on PCEs, other areas, such as moral enhancement, have been discussed to some degree but lack significant empirical study (at least on the basis of discovering technological means to modulate human behaviour safely and effectively[34]). In many cases the field remains more of a promise than a reality. However, progress is accelerating as enhancement possibilities are discovered for therapeutic interventions such as cochlear implants[35] and artificial nerves. HET does not yet have an established body of techniques, subfields, etc., making the definitions and demarcations more important for HET than for the other fields SIENNA is researching because the ultimate direction the field may develop in remains difficult to foresee. Unlike genomics and AI & robotics, there are no established journals or conference series about the *science* of HET rather than its philosophy or ethics. We anticipate this will change in the near future, but it is important to clarify that HET is far from entrenched.

2.5 Description of subfields and concepts, techniques, etc. used in them

Although human enhancement is an emerging field, it's already an expansive field. Enhancement technologies may boost cognitive capabilities, introduce new physical abilities, or provide greater

[32] Linssen, op. cit. 2011.
[33] Lev, Ori, Franklin G. Miller, and Ezekiel J. Emanuel, "The Ethics of Research on Enhancement Interventions," *Kennedy Institute of Ethics Journal* Vol. 20, No. 2, 2010, pp. 101–113.
[34] There exists a body of evidence that suggests human moral behavior may be influenced, if not determined, by natural occurring substances in the human organism such as oxytocin, synthetic drugs such as Propranolol (see Terbeck, Sylvia, Guy Kahane, Sarah Mctavish, Julian Savulescu, Philip J. Cowen, and Miles Hewstone, "Propranolol Reduces Implicit Negative Racial Bias," *Psychopharmacology* Vol. 222, No. 3, 2012, pp. 419–424.), or genes such as the *MAOA* gene (see Forzano, Francesca, Pascal Borry, Anne Cambon-Thomsen, Shirley V Hodgson, Aad Tibben, Petrus De Vries, Carla Van El, and Martina Cornel, "Italian Appeal Court: a Genetic Predisposition to Commit Murder?," *European Journal of Human Genetics* Vol. 18, No. 5, October 2010, pp. 519–521; Pieri, Elisa, and Mairi Levitt, "Risky Individuals And The Politics Of Genetic Research Into Aggressiveness And Violence," *Bioethics* Vol. 22, No. 9, 2008, pp. 509–518; Starr, Douglas, "Linking Crime and Genetics Need Not Be an Act of Eugenics – Douglas Starr | Aeon Essays," *Aeon*, Aeon, March 25, 2018. https://aeon.co/essays/linking-crime-and-genetics-need-not-be-an-act-of-eugenics).
[35] NIH Publication No. 11-4798. "Cochlear Implants". *National Institute on Deafness and Other Communication Disorders*, 2013.

control over individual affect, just to name a few of the possible outcomes. Because the variety of outcomes is so vast, it is necessary to divide the field into subcategories. In the following sections, we will describe such subfields to encompass the full range of the field of HET. First, we will introduce six subcategories of enhancement targets: cognitive, affective, moral, physical, cosmetic & longevity. Each of these categories were previously discussed in the introduction; in the following section, we will explain them in full. Then, we will discuss the primary expected delivery methods for enhancement: biomedical/pharmaceutical, machine-based and genetic. Finally, we will discuss the primary expected locales for enhancement: healthcare, education, workplace, military/defence and home/recreation.

2.6 Categorizing enhancements based on their target

In this section, we will introduce six subcategories for HET based on the target, or goal, of the application. For example, if an enhancement is designed to increase one's physical stamina then the increase of physical stamina is its target.

Cognitive enhancements are interventions that improve cognitive abilities. Potential targets for cognitive enhancement are *intelligence, clarity* and *creativity*. Intelligence enhancements improve capabilities associated with intellectual abilities, such as critical thinking, reasoning, memory[36] or comprehension of ideas. Clarity enhancements are primarily related to focus but can also apply to enhancements that increase abilities associated with maintaining rigor during cognitive tasks. Creativity enhancements improve inventiveness, artistic ability, design-related tasks, or, more broadly, the ability to think of new ideas or concepts.

It may be possible for a future cognitive enhancement intervention to increase capabilities across these sub-categories, such as increasing both clear-headedness (clarity) and memory (intelligence). Modern cognitive enhancements are known to provide only mild boosts to a limited range of capability.[37] It will likely be necessary for scientific understanding of, for instance, the neurological basis of inventiveness to improve before a cognitive enhancement can be developed to increase such a trait. Therefore, clarity enhancements are the most likely category of cognitive enhancements expected to develop soon, whereas creativity enhancements may be a long way off.

Affective enhancements are interventions that improve and/or provide greater control over a human's affect. Potential targets for affective enhancement are *mood, emotion* and possibly *empathy*. Mood enhancements give a user control over their mood, such as by allowing a user to quickly, perhaps even instantaneously, transition from feeling anxious about work while at home to feeling more comfortable. Emotional enhancements alter the user's emotional state, for example by making a user feel happy quickly, or perhaps even instantaneously, after taking a pill. In addition, emotional enhancements may be used with a clear objective to allow a user to experience what they perceive as the 'correct' emotion in some situations, i.e., when a woman who has recently given birth does not have the affective feelings for her baby that she expects.[38] An important research domain in affective enhancement is so-called 'love drugs' designed for individuals to improve their affective relationships. Empathy may be another subcategory for affective enhancements. However, the empirical

[36] We remain agnostic about whether memory and intelligence necessarily amount to the same kind of ability; for our purposes, we have associated memory with intelligence in this HET category as a matter of practicality. It may be that memory enhancements deserve their own subcategory within cognitive enhancements if memory is not linked to intelligence.
[37] Battleday, R.m., and A.-K. Brem, "Modafinil for cognitive neuroenhancement in healthy non-Sleep-Deprived subjects: A systematic review," *European Neuropsychopharmacology* Vol. 26, No. 2, 2015, p. 391.
[38] Kahane, Guy, "Reasons to Feel, Reasons to Take Pills," *Enhancing Human Capacities*, 2014, pp. 166–178.

components of empathy, whatever they are, may require more than improving or modulating affect, possibly suggesting a further category of 'behavioural enhancements'. Such a category is problematic to include at this stage because many, if not all, enhancements that could modify or enhance behaviour are likely to better fit into other subcategories. If the field develops to include robust enhancements that allow the modulation or enhancement of a specific type of behaviour alone, perhaps via a drug that improves punctuality without any other changes, it may then qualify as a separate category.

Moral enhancements are interventions that modulate or otherwise allow one to improve their moral bearing. Potential targets for moral enhancement range from *limited* enhancements, for example interventions designed to 'correct' behaviours considered deviant in one's society, to more *robust* interventions that greatly alter or allow for the modulation of moral deliberation. Although literature, whether in the media, via government policy or elsewhere, rarely labels existing interventions as moral enhancements, arguably the use of anaphrodisiac drugs to improve sexual behaviour may be considered a form of limited moral enhancement.[39] Another class of existing limited moral enhancements may be drugs that reduce implicit bias.[40] Robust moral enhancements have been the focus of significant debate by ethicists over the last decade.[41] A successful moral enhancer of this kind will be an intervention that alters many of the underlying characteristics within an individual that, when combined, result in enhanced moral decision-making to improve the individual's overall moral outcomes.

Physical enhancements are interventions that improve or introduce new physical abilities. Potential targets for physical enhancement are *performance*, *endurance*, or the *addition of new abilities (additive)*. Performance enhancements increase the capacity to effectively complete physically demanding tasks, like running quickly or lifting heavy objects. Endurance enhancements increase the capacity to engage in physically demanding tasks for extended periods of time. In some cases, performance and endurance enhancements will overlap; i.e., a single intervention may increase performance in such a way that also improves endurance, or vice-versa. Additive enhancements add new physical abilities that an individual could not have without the enhancement, i.e. adding novel abilities, like seeing clearly in the dark.

Several physical enhancers already exist, but many are heavily regulated with strict laws regarding usage and some are even outlawed, often due to negative side-effects such as addiction. Although balancing improvements against negative side-effects is a challenge for all categories of enhancement, this is especially true for physical enhancements. Furthermore, the introduction of novel new abilities may result in special challenges regarding the accessibility or availability of additive enhancements.

Cosmetic enhancements are interventions that improve the cosmetic traits of a human being. There are two subcategories of cosmetic enhancement: *aesthetic* and *body modification*. Aesthetic

[39] See for instance Cochrane, Joe, "Indonesia Approves Castration for Sex Offenders Who Prey on Children," *The New York Times*, The New York Times, May 25, 2016. https://www.nytimes.com/2016/05/26/world/asia/indonesia-chemical-castration.html; Reilly, Jill, "Paedophile Nursery Worker Asks to Be Chemically CASTRATED to Curb His Sexual Urges ... and Says He'll Take His Human Rights Case to Strasbourg If He Has To," *Daily Mail Online*, Associated Newspapers, February 20, 2014. http://www.dailymail.co.uk/news/article-2563908/Paedophile-nursery-worker-asks-chemically-CASTRATED-curb-sexual-urges-says-hell-human-rights-case-Strasbourg-to.html; BBC. "ADHD Treatment 'May Reduce Risk of Criminal Behaviour'," *BBC News*, BBC, November 22, 2012. http://www.bbc.com/news/health-20414822.
[40] Terbeck, Sylvia, et. al., op. cit., 2012.
[41] Persson, Ingmar, and Julian Savulescu, "Getting Moral Enhancement Right: The Desirability Of Moral Bioenhancement," *Bioethics* Vol. 27, No. 3, 2011, pp. 124–131.

enhancements improve one's physical features to better accord with social ideals, such as cosmetic plastic surgery. Body modification entails augmenting oneself by introducing new (primarily) cosmetic features, such as 'installing' magnetic fingertips. Whether a body modification best fits the category of cosmetic enhancement or physical enhancement will depend on how the enhanced or new capability will be used: if it is merely a novelty, it is not a physical enhancement, but if it adds or improves functionality in a more meaningful way then it may also be a physical enhancement. Advances in prosthetic technology may lead some individuals to seek prosthetic limbs that enhance their performance beyond biological limbs and also appeal to their unique aesthetic sensibility, further blurring the line between cosmetic and physical enhancements.[42]

Longevity enhancements are interventions that extend a human's lifetime. Longevity enhancements may be *preventative* or may improve one's *senescence* or *durability*. Preventative enhancements stop or reduce negative effects of disease or disability, such as a vaccine. Senescent enhancements stop or slow the aging process of the body. Durability enhancements improve one's ability to survive or recover from harm or damage. Longevity enhancements are one of the hardest categories of HET to classify since almost all modern technologies that could arguably fit the category are better understood as and seen as treatments, while the expected enhancements in the category tend to be highly visionary and may often fall outside our focus on HETs expected within the next 20 years.

Category	Sub-category	Example (often speculative)
Cognitive	Intelligence	Memory booster
	Clarity	'Smart' drugs, such as methylphenidate
	Creativity	Imagination booster
Affective	Mood	Psychopharmaceutical to improve state of mind
	Emotion	Psychopharmaceutical to induce happiness
	Empathy	Neurostimulation resulting in becoming more appreciative of other perspectives
Moral	Limited	Anaphrodisiac to curb deviant sexual behaviour
	Robust	Intervention to ensure one makes consequentialist or utilitarian choices in every circumstance
Physical	Performance	IPED allowing one to lift larger weights
	Endurance	IPED allowing one to run longer
	Additive	Surgical intervention allowing one to see in the dark
Cosmetic	Aesthetic	Plastic surgery: improved appearance
	Body modification	Magnetic fingernails
Longevity	Preventative	Vaccine: immunity to a disease
	Senescent	Pharmacological intervention to keep one's body from aging
	Durability	Surgical intervention allowing one to survive in the vacuum of space

Table 5: Categorised examples of human enhancement

2.7 Enhancement delivery methods

HET may be delivered in a variety of ways, such as via biomedical or pharmaceutical means, machine-based augmentation, or genetic interventions. Biomedical or pharmaceutical delivery may include

[42] Gales, Alain, "Alternative Prosthetics That 'Speak from the Soul'," *BBC News*, BBC, January 5, 2015. http://www.bbc.com/news/av/magazine-30551860/alternative-prosthetics-that-speak-from-the-soul. (especially at 03:40min): "...*the conversation changes from one of pity to one of amazement...*"

surgeries or other invasive medical procedures, non-invasive technological measures, pharmaceuticals or nanotechnology. Invasive medical procedures may result in the installation or administration of HET, such as deep-brain stimulation (DBS). Non-invasive technological measures may include maintenance or upgrading previously installed or administered HET devices. Pharmaceuticals may include the use of pills, injections or other common medical delivery methods (i.e., ointments, liquids, etc.) that result in enhanced abilities. Eventually, nanotechnology may become a delivery mechanism for HET, such as the hypothetical introduction of artificial blood laced with nanomachines to increase physical performance.[43]

Machine-based augmentation may include advanced prosthetics or brain-computer interface (BCI) devices. Although some advanced prosthetics require surgical installation today, it is becoming increasingly possible for prosthetic devices to not require invasive installation. Likewise, robust modern BCIs require invasive surgery; however, it may be possible that future devices that do not require surgery may become available. Wearable devices and enhancement-producing software also fall under machine-based augmentations.

Genetic interventions are seen by some as one of the most promising fields for the development of HET. It is possible that in the future modern interventions, such as pre-implantation genetic diagnosis (PGD), could develop to allow for enhancement outcomes, such as via embryo selection, although regulations currently enforce against utilizing PGD for enhancement. A tool like CRISPR Cas-9 could theoretically be further developed for safe genetic editing for enhancement. One important distinction for genetic interventions is somatic versus germline gene editing. Gene editing in somatic cells (i.e. almost all cells that are not sperm or egg) is performed in cells that will not be transmitted to future generations. It is currently thought that editing somatic cells will not result in having the modification inherited.

Method for delivery	Description	Examples
Biomedical/pharmaceutical	Invasive medical procedures, non-invasive technological measures, pharmaceuticals, nanotechnology	Neuro-stimulation, PCEs, IPEDs, artificial blood
Machine-based augmentation	Prosthetics, BCIs, wearables	AI-enhanced prosthetic limbs, neural implants, intelligent personal assistants (IPAs)
Genetic interventions	Genetic engineering, reproductive interventions, embryo selection	Pre-implantation genetic diagnosis, CRISPR Cas-9, ‘designer babies’

Table 6: Expected methods of delivery for HETs

2.8 Enhancement domains

Another way to contemplate HET is to consider the likely locations for its use. Primary expected locales for enhancement are healthcare, education, the workplace, military/defence and home or recreation. It is important to note that certain HETs are likely to fit several of these domains, and thus stand as cross-sectional enhancements. Although healthcare tends to focus on treatment, healthcare providers may be the primary source of receiving and/or installing enhancements during the research phase. Providing safe enhancements may open a new revenue stream for the healthcare industry that could

[43] Freitas, Robert A., “Exploratory Design in Medical Nanotechnology: A Mechanical Artificial Red Cell,” *Artificial Cells, Blood Substitutes, and Biotechnology* Vol. 26, No. 4, 1998, pp. 411–430.

subsidize costly life-saving procedures. Students may use cognitive enhancements to try improving study or exam results, whereas teachers or researchers may use enhancements to try improving their focus to increase job performance. Similar enhancement uses may occur more widely in the workplace in general, in addition to advanced prosthetic or wearable technologies giving workers in some professions 'better-than-normal' capability to do their job, such as by allowing construction workers to better complete physically-demanding tasks. Without gesturing to the morality behind the possibilities, enhancements may be used in a variety of ways by the military to improve the chances for soldiers to survive or to improve their ability to complete their missions. Furthermore, military funding is one of the primary sources driving empirical scientific work on HET forward.[44] At home, enhancements may be used for recreational purposes: affective enhancements could be used to allow an individual to enter a specified disposition, perhaps to increase their emotional lability prior to watching a critically-acclaimed movie, or decrease emotional lability prior to making a difficult personal decision. Many other general examples can be imagined. The ideas in this section are meant to serve as a demonstration of possibilities. In chapter 3, we will explore specific examples of existing and likely HETs in greater detail.

2.9 Discussion of present & future scientific/technological challenges

Presently, the field of human enhancement remains highly visionary. It is likely that progress has been slow due to the difficulty of many scientific and technological challenges. Genomics and AI & robotics, the other fields under investigation by SIENNA, are at further stages in their development. Below, we will discuss many of the challenges facing the field of HET.

One challenge is that approval for development and innovation in HET is tricky because the vast majority of regulation for such research is geared toward the development of treatments. The use of physical enhancements for performance has been highly regulated due to their inappropriate use in professional sports, where the use of HET is often seen as cheating. Some of the moral debate on HET has revolved around the issue of cheating or, more broadly, on fair use. These issues may have a negative impact on the desirability of developing physical enhancements. The development of enhancements for the military may lead to similar social disapproval. Because many possible HETs could be used by the military, these worries could affect a large swath of potential research projects. Ultimately, it seems unlikely that labs could receive the necessary funding for research on non-therapeutic enhancements required to produce significant results, unless new regulatory policy for HET is introduced, whether by a government agency or other entity, to guide such efforts.

Reluctance from health scientists and practitioners who interact with researchers in healthcare may also involve the violation of the Hippocratic oath, i.e. the widespread practice in the healthcare profession of upholding a traditional code of ethics. Although it's not necessarily the case that the development or use of HETs would involve violations of professional ethical codes, this may sometimes occur. For example, such a violation may occur if a patient requests an IPED that has a high risk of serious side-effects with the goal of improving a superficial trait or gaining an unfair advantage over others in their profession. As long as the risks of any individual HET remains unclear, researchers and practitioners may remain hesitant to help patients take risks that could diminish their wellbeing due to negative side-effects.

[44] Reardon, Sara, "The Military-Bioscience Complex," *Nature* Vol. 522, June 11, 2015, pp. 142–144. https://www.nature.com/polopoly_fs/1.17726!/menu/main/topColumns/topLeftColumn/pdf/522142a.pdf.

Although it may seem obvious, another major challenge for HET relates to complexity. Many HETs will require complex interactions within the human body to achieve desirable results. Although scientific knowledge regarding the human body continues to increase, there remain many areas that are not yet well-understood, especially with regards to several cognitive functions, such as memory and creativity. Although it is easy to imagine that a pill could someday exist to boost discrete cognitive functions, the scientific knowledge required to effectively increase such functions will almost always be highly complicated. Furthermore, merely increasing a human capability isn't enough: effective HETs must also avoid introducing negative side-effects from their use. Many ethicists agree therapeutic research can proceed so long as a desirable cost-benefit ratio is achieved[45]; for an enhancement meant for healthy persons, however, the adequate cost-benefit ratio, whatever it is, may be harder to achieve.

There is also a theoretical challenge standing in the way of developing HETs. Namely, there is a widely negative association attributable to eugenics, and some HET sceptics have argued that HET, or at least certain HET, such as those delivered via biotechnology, is eugenics.[46] This association might be one reason why it is difficult at the moment to find scientists who willingly identify as HET researchers. The social wrongs committed in the past in the pursuit of eugenic goals exist as a blemish in human history. Distinguishing modern HET, which may result in the achievement of eugenic goals, from this history may prove to be a lengthy and difficult process, although some philosophers have already begun trying to make the case.[47]

As specific HETs become safer and cheaper to produce, scalability may emerge as another challenge. Some enhancements may require rare or highly individualized materials, making it impossible to scale production or decrease costs. It's worth noting that little empirical work has been done on HET with regards to market expectations. Resource scarcity remains an issue for some treatments of rare diseases, but whereas there are few who would argue against producing such treatments even if they are expensive there are different social factors involved when considering HET. Conversely, if a large variety of HET products become available the market could become oversaturated, requiring complex regulation to safeguard consumers from potentially dangerous HET products. Even with legal regulations in place, widespread development of HETs could introduce a black market of cheap and/or unsafe alternatives to the professionally produced and marketed products in the nascent industry. If there are separate pharmaceutical HETs available to improve focus, memory consolidation, muscle development, emotional lability, youthful skin and to slow aging, all directly available to consumers, it is unlikely that all of these enhancements will be safe to use concurrently, especially if there are slightly different options available for each trait from different producers, which could have consequences similar to polysubstance abuse.[48]

One of the recurring arguments against the development of HET is based on scepticism about the accessibility for HET. Novel biomedical advances tend to be expensive. Could there be effective measures to ensure that enhancement options will become available to more than the wealthiest members of society? Although speculative, it could be that some future enhancements will require

[45] Lev et. al., op. cit. 2010.
[46] Vizcarrondo, Felipe E., "Human Enhancement: The New Eugenics," *The Linacre Quarterly* Vol. 81, No. 3, 2014, pp. 239–243.
[47] Agar, Nicholas, *Liberal Eugenics: in Defence of Human Enhancement*, Blackwell, Oxford, 2004; Buchanan, Allen, Dan W. Brock, Norman Daniels, and Daniel Wikler. *From chance to choice: Genetics and justice*. Cambridge: Cambridge University Press, 2000. Glover, Jonathan. *Choosing children: Genes, disability, and design*. Oxford: Clarendon, 2006.
[48] Brennan, Rebekah, John S.g. Wells, and Marie Claire Van Hout, "The injecting use of image and performance-Enhancing drugs (IPED) in the general population: a systematic review," *Health & Social Care in the Community* Vol. 25, No. 5, 2016, pp. 1459–1531.

rare materials making it impossible to decrease costs below a certain line, making this a practical challenge as well as an ethical one. The logistics of providing HET across borders to populations beyond the wealthiest countries could prove insurmountable in the short-term.

Although ideally HET would be developed to improve the well-being of every user, the emerging field is susceptible to dual-use risks. For example, enhancements that quickly or immediately change the mood or emotional state of a user could be forcibly administered without consent, knowingly or unwittingly, in a similar way to what are casually termed 'date-rape drugs.' If a soldier is equipped with HETs to make them more effective at killing enemy combatants and this soldier's mental health deteriorates after returning to civilian life without deactivating the enhancements they may prove more dangerous than non-enhanced civilians. Furthermore, if the field yields interventions that successfully enhance capabilities, the same knowledge allowing for some HETs may be used to develop interventions to *de*-enhance, or deliberately debilitate, the same capacities in individuals. These are just three examples of potential dual-use issues in the field.

Perhaps most difficult of all, it's hard to know what is possible when it comes to HET, especially in the long-term. Much of the moral debate on HET touches on interventions that, based on current scientific knowledge, may not exist for centuries (if ever), or, if there is a genuinely revolutionary innovation, might become available in less than a decade. Incremental progress is likely, but there may be breakthroughs that greatly advance the field.[49] Although it seems far-fetched to believe there could be an HET available in the next few years that genuinely enhances creativity or stops aging, it's not unthinkable if the right breakthroughs are made in the necessary subfields. This uncertainty makes it especially difficult to prepare effective regulation, as policymakers will have to decide whether (or not) to anticipate unlikely but possible future developments.

2.10 Possible developments in the field

In what follows, we will endeavour to assess the conceivable developments in the field, first by considering the possibilities in general, and then in the subsequent chapter by examining specific technologies. Within the next five to ten years, we expect some HETs that can improve single capabilities to enter the consumer market, at least in the United States and in at least some parts of the European Union. Existing psychopharmaceuticals currently undergoing research on their enhancement potential via off-label usage could be rebranded for non-therapeutic use if they prove safe and possible to regulate; in fact, some 'smart drugs' are already beginning to enter the consumer marketplace in certain regions.[50] Some of the first fully non-therapeutic enhancement technologies are becoming available and we expect this trend to accelerate in the near future, perhaps in the form of reliable wearable or non-invasive devices that interact with the human brain. One concern regarding this development is the potential for 'medicalization' of enhancement products, whereas by medicalization we mean the practice of companies lobbying to convince the public that a circumstance previously not treated as a medical disability requires treatment. Although strict regulations exist limiting direct marketing of treatments in the EU, the same cannot be said for other regions, such as

[49] Masci, David, "Human Enhancement," *Pew Research Center: Internet, Science & Tech*, July 26, 2016. http://www.pewinternet.org/essay/human-enhancement-the-scientific-and-ethical-dimensions-of-striving-for-perfection/.
[50] See, for example, Brain Enhancement Advisor, "Study Buddy," *Study Buddy*, BrainEnhancementAdvisor.org, March 15, 2018. https://www.brainenhancementadvisor.org/smart-pill-reviews/study-buddy/; Yalaniz, Mucahit, "Optimaliseer De Hersenen Met Braincaps," *Braincaps*, 2018. https://braincaps.nl/.

the United States. In addition, it remains to be seen how easily such regulations could be adapted for enhancement products that cannot be used for treatment.

As the first wave of HETs become available to consumers, market competition may begin to drive the costs of enhancement options lower in existing markets, opening access to HET to a larger portion of the population globally. The advance of prosthetic technologies, alongside decreasing costs of such machinery, could result in healthy persons choosing to install prosthetic limbs or artificial replacement organs to augment their abilities, perhaps in some cases involving the deliberate amputation of healthy limbs. Depending on whether or not this practice becomes widespread, an additional impact could be a deeper segregation in professional sports, perhaps resulting in new 'augmented' leagues, although changes to deeply entrenched institutions like professional sports organizations may not occur within the next decade. If the cost of cognitive enhancement options becomes low enough, society could adopt an expectation to use such enhancements in certain circumstances, such as for college students or workers employed in fast-paced professions.

We would like to note the difficulty to identify specific market expectations for HET. Although some forecasts exist for specific technologies, we were unable to find compelling predictions for market trends regarding the wider field of HET. We suspect this is due to the emerging nature of the field: many applications exist more as a promise than in reality, making it especially difficult to predict the costs or other economic factors that could follow once the technologies move out of the R&D stage.

As previously mentioned, it is tremendously difficult to accurately predict long-term developments. In the next 10-20 years, incremental advances in HET that improve discrete capabilities may lead to some options that improve many different capabilities in the same intervention. The convergence of several enhancements could improve the viability for humans to survive long-term in low or zero-gravity environments, advancing space exploration endeavours, although this will probably be limited to short-range missions. The convergence of advanced AI, robotics and HET could accelerate the development of computerized neural interfaces, although significant breakthroughs are needed first, as well as careful research to ensure safety.

3. Present & future applications

In this section, we will discuss many of the present and expected future human enhancement applications. First, we will propose a timetable of HET applications by enhancement target. Then, we will briefly discuss where work on HET currently is and is expected to go with regards to techniques. The rest of this section contains a discussion based on the domain of application; in particular: healthcare, education, the workplace, military/defence and home or recreation. Several enhancements may fit within more than one domain. To avoid repetition, we will try to discuss enhancements in their primary domain and will make note if they are expected to be used extensively in other domains.

3.1 Timetable of applications by enhancement target

We expect significant progress to occur in HETs within the next twenty years. Perhaps the most important anticipated advance will be the establishment of 'Human Enhancement' as an active field of scientific research and development, rather than the current state in which developments in HET tend to occur as a side-effect of advances in other technological fields, such as PCE developments in healthcare or neurostimulation techniques in neuroscience. Below, we deliver an optimistic timetable of expected developments in HET. It is entirely possible that several of our predictions will prove to be inaccurate, especially if scientific or technological challenges (as discussed in section 2.9 above), along with ethical, legal and human rights challenges yet to be researched in further SIENNA WP3 work, delay or impede anticipated advances.

In the next five years, we don't expect to see many 'new' HET applications; rather, we expect existing applications to undergo the necessary research to prepare applications such as PCEs and neurostimulation for the consumer market in Western societies. Advances in prosthetics will begin to endow patients with capabilities beyond normal biological standards, but we expect such prosthetics to remain in use only by patients who have lost limbs within this timeframe. Perhaps the most promising arena for 'new' applications in the next five years will be affective enhancements.[51]

In five to ten years, we expect existing enhancements that are currently unsafe for conventional use to become safe, such as IPEDs. Developments in affective enhancement will pave the way for more robust moral enhancements. Advances in computer technologies will lead to Wi-Fi implants granting new options to connect to and interact with high-tech devices. Advances in AI will improve prosthetics, perhaps leading the first healthy individuals to undergo surgery to replace healthy biological limbs with AI-augmented prosthetics. In this time frame, many of the initial HETs expected to reach the Western consumer market in the next five years will begin to enter worldwide markets.

In 10 to 20 years, first-generation implanted neural interface (INI) HETs may become available, combining many of the features of existing smart technologies and expected Wi-Fi implants into a type of device that directly interacts with a human's brain. Development of affective enhancements will continue to improve, granting users full control over their dispositions via HET. In this period, we also expect to see the first HET interventions that add new capabilities to humans to begin entering Western markets, such as night-vision. Advances in neuroscience and computer technologies may enable the storage and retrieval of biological memories.

In 20 or more years, full brain uploading may become a possibility, although serious hurdles, such as development of high-resolution brain-scanning and a deeper understanding of the constituents of consciousness, must be overcome, which may prove to be impossible. It is more likely that advances in genomics will lead to a variety of longevity enhancements at this stage, such as allowing humans to survive long-term in low-gravity environments. Advances in affective enhancements will finally enable truly robust moral HETs. It is important to note that SIENNA does not plan to focus on reaching conclusions about HET developments that are expected in no fewer than 20 years.

Period	Expected applications
Next 5 years	• Consumer-market PCEs in Western nations • One or more neurostimulation device(s) widely endorsed for safe enhancement use by neuroscientists • Prosthetics that narrowly improve patients' capacities beyond the standard performance of biological limbs • Affective enhancements that target discrete affective states • Simple cosmetic body modifications, i.e. magnetic fingertips
5-10 years	• Safe IPED endorsed by healthcare professionals • Limited moral enhancement

[51] This may be surprising as cognitive enhancements appear to be receiving much more focus presently than affective enhancements. However, in this case 'new' is meant to indicate a category that is currently underdeveloped; therefore, since cognitive enhancements are actively being developed, we anticipate affective enhancements to be the next category to see a major increase in development in the next five years.

Period	Expected applications
	• Wi-Fi enabled microchip implants • Advanced AI-assisted prosthetics • Consumer-market PCEs worldwide
10-20 years	• HET implanted neural interfaces (INIs) • Affective enhancements that allow full control of one's disposition • Additive enhancements, i.e. intervention for night-vision • Biological memory storage/retrieval system
20+ years	• Full brain uploading • Durability enhancements for low-gravity survival • Robust moral enhancement

Table 7: Timetable for HET

3.2 Evaluation of HET by technique

As discussed in Section 2.7 above, we have identified a number of delivery methods for HETs, namely: biomedical or pharmaceutical techniques, machine-based augmentations and genetic interventions. At present, most existing HETs fit under the biomedical/pharmaceutical category, although a number of machine-based augmentation technologies are under development and genetic interventions could contain the most robust HETs in the future. Individual applications mentioned in this section will be further explained in subsequent sections in the chapter, and thus are not meant to determine any new subcategories for HET.

Biomedical/pharmaceutical HETs are often first developed as treatments in healthcare. Biomedical procedures, such as surgery or other invasive medical procedures, non-invasive technological measures or the use of nanotechnology in the human body, as well as pharmaceutical interventions account for many modern applications. In fact, one of the most widely-discussed HET applications, psychopharmaceutical cognitive enhancement (PCE), fits fully within this technique category. Additionally, this category includes: neuromodulation, image & performance-enhancing drugs (IPED), artificial blood, modern prosthetics, body modifications, cosmetic surgery and most sex enhancements (all of which will be discussed in more detail later in this chapter). All of these applications are at least undergoing research if not already available in some form. Three-dimensional bioprinting is expected to enable new HET interventions within the next five to ten years, and neural implants, memory enhancements and moral enhancements are likely to result in new HET interventions within the next 10 to 20 years. In the near future, unanticipated biomedical or pharmaceutical HET interventions may develop alongside new treatments discovered to positively enhance healthy patients. Biomedical/pharmaceutical techniques are likely to be necessary to install and administrate complex HETs in the subsequent categories.

Machine-based augmentation is an emerging HET technique. Existing machine-based HETs include: brain-computer interfaces (BCIs), speech technologies, head-mounted devices, intelligent personal assistants (IPAs), subdermal RFID keys and wearables. In the next five to ten years, machine-based augmentations may also include AI-assisted prosthetics, biological camouflage and bioweapons, along with more robust versions of existing machine-based technologies. The main difference between machine-based augmentations and biomedical/pharmaceutical techniques is the lack of any requirement of biomedical procedure for machine-based augmentations. This is why modern prosthetics better fit the biomedical/pharmaceutical category rather than the machine-based augmentation category. As HETs become more widely available, we expect machine-based augmentation to become a more dominant category for elective human enhancement as long as machine-based augmentations successfully enter the consumer market.

The only widely-used genetic interventions that fit our definition of HET today is pre-implantation genetic diagnosis, which is commonly associated with the reproductive technology in-vitro fertilization. However, advances in genomics are expected to enable advanced preventative medicines and anti-aging interventions at some point in the future, although we note that these may not be developed for more than 20 years and thus may fall outside the scope of SIENNA's research objectives. We remain hesitant to speculate on genetic interventions beyond these at this stage, as it remains uncertain whether or not theoretical genetic enhancements, such as genetic engineering via CRISPR-Cas9, will or will not be developed for human enhancement in the near future. As SIENNA has another report on the state-of-the-art of genomics, we defer to the findings of *SIENNA D2.1: State-of-the-art review for genomics* regarding further genetic interventions with enhancement potential.

3.3 Healthcare applications

One of the largest human enhancement applications in healthcare is **pharmaceutical enhancement**. Traditionally, pharmaceuticals are developed for healthcare. Psychopharmaceuticals commonly prescribed to treat depression or anxiety disorders, like selective serotonin reuptake inhibitors (SSRIs), have been the subject of limited study on healthy patients for enhancement. However, results tend to show little if any affective enhancement for healthy subjects, with the exception of increases in extraversion, although more research is needed.[52] In the future, the range of effective affective enhancements is likely to increase, although it's difficult to speculate on which affective states may become possible to enhance first, whether it's compassion, joy, contentment or any number of other affective conditions. It may be the case that an initial breakthrough could pave the way for a wide variety of affective enhancements, or new targets may become viable only incrementally.

Beta-blockers, such as Propranolol, have also been studied as pharmaceutical enhancers. Although the evidence for cognitive enhancement from such drugs is limited, beta-blockers are known to augment affect by, for example, helping to relieve hand tremors for musicians.[53] Empirical studies have also shown that beta-blockers can dampen the emotional intensity of an event if administered soon after the event occurs.[54] Although such evidence is hardly suggestive for enhancement purposes, it stands as evidence for pharmacological memory manipulation, which suggests it is plausible that memory-enhancing pharmaceuticals could be developed in the future. In addition to the modulation of affect, Propranolol is also a candidate for limited moral enhancement by reducing implicit racial bias.[55]

Although the evidence of modern drugs for **memory enhancement** is lacking, many researchers are investigating therapies for degenerative conditions such as Alzheimer's disease that may result in pharmaceuticals to enhance the memory of healthy subjects. Liao discusses a variety of 'memory manipulation' techniques that may come to bear in the near future, some enhancing and some not.[56]

[52] Ilieva, Irena, "Enhancement of Healthy Personality Through Psychiatric Medication: The Influence of SSRIs on Neuroticism and Extraversion," *Neuroethics* Vol. 8, No. 2, 2014, pp. 127–137.
[53] Beversdorf, D Q., J D. Hughes, B A. Steinberg, L D. Lewis, and K M. Heilman, "Noradrenergic modulation of cognitive flexibility in problem solving," *NeuroReport* Vol. 10, No. 13, 1999, pp. 2763–2767.
[54] Kolber, Adam J, "Therapeutic Forgetting: The Legal and Ethical Implications of Memory Dampening," *Vanderbilt Law Review* Vol. 59, No. 5, 2006, pp. 1559–1625.
[55] Terbeck, Sylvia, et. al., op. cit., 2012.
[56] Liao, S. Matthew, "The Ethics of Memory Modification," in Sven Bernecker and Kourken Michaelian (eds.), *The Routledge handbook of philosophy of memory*, Routledge, London, 2017, pp. 373–382.

For example, research may lead to enhancements that improve memory consolidation, increase the speed of memory retrieval, or expand one's maximum amount of information stored in biological memory. A recent study with a neural implant in epilepsy patients reliably improved word recall by about 15 percent, although further research is needed before such a device could be used as a consumer-market enhancement.[57] Memory enhancement is likely to play a large role in education and the workplace as well as in healthcare.

Existing **limited moral enhancements** include chemical castration and some drugs for treating ADHD that appear to reduce recidivism among former detainees.[58] Regarding more **robust moral enhancements**, the foundations of moral behaviour remain a hotly debated topic in philosophy and the sciences; it's likely a robust moral enhancer will need to target a variety of affective and/or behavioural conditions, meaning such a moral enhancement application is likely to emerge only after other affective and/or cognitive enhancements are developed. Since the field, especially in neuroscience, appears to be moving forward quickly, it's plausible that robust moral enhancers may become available in one or two decades, but it's too early to narrow predictions further than this. Once healthcare proves moral enhancements are effective, they will be useful in every enhancement domain.

Brain-computer interfaces (BCIs) are systems that translate 'brain signals into new kinds of outputs'[59] and thus bridge communication between the brain and an external device. BCIs recently have started to make their way into the military domain, initially aimed at restoring the function of soldiers after injuries sustained in combat. Animal studies have shown that BCIs could successfully interface with both movement and communication prosthetics concurrently, promising enhanced performances from both BCIs and prosthetics within a human.[60] The Pentagon's Defense Advanced Research Projects Agency (DARPA) has claimed a big success with the development of a 'mind-controlled prosthetic robotic arm.' This robotic arm is operated through electroencephalograph (EEG) signals within the motor cortex and the user is able to identify touch based on communication from the artificial arm to the sensory cortex of the user's brain.[61] The main challenge is the development of wireless BCIs for such applications. Moreover, the calibration of the system has a long learning curve, which requires constant clinical supervision.[62]

Although the majority of modern BCI research is conducted with therapeutic goals, especially for physical rehabilitation, some empirical studies have been conducted on healthy subjects that show enhancement potential. For example, a BCI study utilizing intracranial electroencephalography (iEEG)

[57] Carey, Benedict, "A Brain Implant Improved Memory, Scientists Report," *The New York Times*, The New York Times Company, February 6, 2018. https://www.nytimes.com/2018/02/06/health/brain-implant-memory.html.
[58] Cochrane, op. cit. 2016; Reilly, op. cit. 2014; BBC, op. cit. 2012.
[59] Wolpaw, Jonathan R., and Elizabeth Winter Wolpaw, "Brain–Computer Interfaces: Something New under the Sun," *Brain–Computer Interfaces: Principles and Practice*, 2012, pp. 3–12.
[60] Kotchetkov, Ivan S., Brian Y. Hwang, Geoffrey Appelboom, Christopher P. Kellner, and E. Sander Connolly, "Brain-Computer Interfaces: Military, Neurosurgical, and Ethical Perspective," *Neurosurgical Focus* Vol. 28, No. 5, 2010.
[61] Umair, Aroosa, Ureeba Ashfaq, and Muhammad Gufran Khan, "Recent Trends, Applications, and Challenges of Brain-Computer Interfacing (BCI)," *International Journal of Intelligent Systems and Applications* Vol. 9, No. 2, August 2017, pp. 58–65.
[62] Rosenfeld, Jeffrey V, and Yan Tat Wong, "Neurobionics and the Brain-Computer Interface: Current Applications and Future Horizons," *The Medical Journal of Australia* Vol. 206, No. 8, January 2017, pp. 363–368.

by Burke *et. al.* concluded their device improved memory encoding for some patients.[63] Furthermore, in 2016 a start-up company was launched to develop prosthetic memory implants for the clinical market, which has shown promising results within rat studies when the device is placed directly in the hippocampus.[64] Future DARPA programs involve perception and control-enhancing BCI binoculars which increase a soldier's sensitivity and will automatically detect the heat signatures of targets up to a range of 10 km and increase the angle of ones view to 120°. Developments in operating robotics trough EEG signals shows promise for BCI controlled vehicles, aircraft and even weapons, letting people operate tools and vehicles with their brain to increase the efficiency of the operation and to limit manual labour.[65] Around 2010, military research was initiated to investigate the possibility of downloading information directly out of the brain, treating it like a hard-drive, and the researchers claim that these technologies will be fully developed by 2025. They aim at using the downloaded brain for pharmaceutical applications, crime investigation and to gain a full understanding of the human body.[66] These applications prove that advances in BCIs are moving research forward for neuroenhancement devices, which we review below.

Speech technologies, such as electrolarynges or text-to-speech, are technologies primarily used to treat patients who otherwise cannot communicate via speech. Software like the Locabulary Lite is primarily used as a therapeutic tool for individuals who cannot or have trouble speaking by allowing a user to select words that are converted to audio output from a mobile phone, while software like the NaturalReader can output text in computer files through a speaker to help users who may have trouble reading. Although the development of these technologies has previously proceeded as treatments, new devices that use lessons from the field are beginning to enter the consumer market with enhancement potential. For instance, there are now devices that can significantly modify a healthy person's voice for entertainment or other purposes, such as software that integrates with communication tools like Skype to digitally alter the user's voice. IBM recently began offering the 'Expressive Text-to-Speech (TTS)' service that adds elements to signal emotional affect to previously expressionless TTS software, which could be combined with other technologies, such as an intelligent personal assistant (IPA)[67], that may enhance a user. Within the military domain, DARPA has already started working on visual and auditory neuroprostheses with BCIs as their base. The 'Advanced Speech Encoding Program' was set up in order to develop silent speech interfaces for acoustically hostile environments. DARPA is simultaneously working on 'Silent Talk,' a program similar to the aforementioned, in which they aim to develop a communication system which will transfer unspoken messages between soldiers on the battlefield trough EEG signals, eliminating the risk of being detected by enemies.[68]

In-vitro fertilization (IVF) is an assisted reproductive technology primarily used when an adult is infertile or wishes to use a surrogate to gestate a pregnancy.[69] The technique alone may be used as an

[63] Burke, John F., Maxwell B. Merkow, Joshua Jacobs, Michael J. Kahana, and Kareem A. Zaghloul, "Brain computer interface to enhance episodic memory in human participants," *Frontiers in Human Neuroscience* Vol. 8, 2015.
[64] Rosenfeld & Wong, op. cit., 2017.
[65] Kotchetkov et. al., op. cit., 2010.
[66] Umair et. al., op. cit., 2017.
[67] Pemberton, Tye, "IBM Makes Watson TTS More Expressive," SpeechTechMag.com, February 29, 2016. http://www.speechtechmag.com/Articles/News/Speech-Technology-News-Features/IBM-Makes-Watson-TTS-More-Expressive--109477.aspx.
[68] Umair et. al., op. cit., 2017.
[69] Oocyte cryopreservation may also be used by individuals who wish to postpone pregnancy to concentrate on career-building or other pursuits; for example, see Bhatia, Rajani, and Lisa Campo-Engelstein, "The

enhancement because clinics in some regions allow prospective parents to choose a sperm sample (and, in some cases, also an egg) from a catalogue that describes the donor. IVF can also be used with **preimplantation genetic diagnosis (PGD)** for parents who are at risk of passing on a negative heritable condition such as Tay-Sachs disease, Huntington's disease or cystic fibrosis to name a few. Although the clear majority of existing laws pertaining to IVF and PGD prohibit use of the techniques explicitly for human enhancement, in theory the techniques could be used in conjunction with genetic engineering to improve one or more characteristics of a child. For more about these techniques, please read *SIENNA D2.1 State of the art review on genomics.*

The development of **advanced preventative medicines** may result in enhancements to average life-expectancy by reducing or eradicating the risk of a wide range of existing maladies. Although it's debatable whether such medicines ought to be considered enhancements at all, or instead seen in the more traditional light as fully treatment-focused therapeutic technology, the species-wide results of advances in this field could have an enhancing effect on humanity. One promising line of research involves advanced tissue engineering utilizing stem cells and bioactive scaffolds for bone regeneration, and the technique is also being explored for regeneration of other vital organs.[70]

Eventually, **anti-aging interventions** may be developed that could further complicate the line between treatment and enhancement. Such interventions may target a variety of biological processes to extend the expected lifespan of an individual. Regardless of the function, the eventual result could be genuine longevity enhancers endorsed by scientists entering the consumer market.

3.4 Education applications

The largest human enhancement application in education today is **pharmaceutical cognitive enhancement (PCE)**. PCEs are also sometimes called psychostimulants, nootropics or smart drugs.[71] Although there is debate about the efficacy of present-day pharmacological enhancements on the whole[72], the perception of enhancement potential of a number of drugs has led to a growing body of empirical research on some pharmaceuticals that may have such potential. The most commonly discussed PCEs are methylphenidate (Ritalin), dextroamphetamine-amphetamine (Adderall) and modafinil (Provigil). Additional PCEs, or at least substances researchers have found to be used for cognitive enhancement, are piracetam, aniracetam and centrophenoxine.[73]

Use of methylphenidate (most often marketed as Ritalin) began in the 1960s and has increased with the acceptance of attention deficit hyperactive disorder (ADHD) diagnoses. An early study on

Biomedicalization of Social Egg Freezing," *Science, Technology, & Human Values*, 2018. http://journals.sagepub.com/doi/abs/10.1177/0162243918754322.

[70] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, "Human enhancement and the future of work", Nov. 2012. https://acmedsci.ac.uk/file-download/34506-12308aca.pdf

[71] Riedel, Wim J, "Psychopharmaceutical Cognition Enhancement," Essay, in Dijstelbloem L.H. Zonneveld and D. Ringoir (eds.), *Reshaping the Human Condition: Exploring Human Enhancement*, Rathenau Institute, The Hague, 2008, pp. 115–122.

[72] Zohny, Hazem, "The Myth of Cognitive Enhancement Drugs," *Neuroethics* Vol. 8, No. 3, 2015, pp. 257–269; Smith, M. Elizabeth, and Martha J. Farah, "Are prescription stimulants "smart pills"? The epidemiology and cognitive neuroscience of prescription stimulant use by normal healthy individuals.," *Psychological Bulletin* Vol. 137, No. 5, 2011, pp. 717–741.

[73] Schifano, Fabrizio, Laura Orsolini, G. Duccio Papanti, and John M. Corkery, "Novel psychoactive substances of interest for psychiatry," *World Psychiatry* Vol. 14, No. 1, 2015, pp. 15–26.

methylphenidate's enhancement potential by Linssen *et. al.* found methylphenidate improved declarative memory consolidation over placebo.[74] A more recent study found methylphenidate (along with modafinil and caffeine) improves high-level competitive chess performance over placebo, suggesting the drugs may genuinely enhance performance of complex cognitive tasks.[75] Dextroamphetamine-amphetamine, most commonly known as Adderall, entered the market under its current name in the 1990s as a treatment for ADHD that helps patients feel more focused. A systematic review article found the drug category that includes Adderall shows 'strong positive effects on verbal learning, delayed memory, vigilance and inhibitory control'.[76] The use of Adderall is either heavily regulated or outlawed in many regions. Modafinil, commonly branded as Provigil, is a wakefulness-promoting drug that entered the market in the 1990s. A systematic review of studies on enhancing effects of modafinil found positive results for 'simple psychometric assessments' in terms of 'executive function' along with 'attention and learning and memory'.[77]

Off-label use of Ritalin, Adderall and Provigil, particularly by college students, has been reviewed several times over the last decade.[78] Depending on the population sample, estimates range from 5-35% of students having consumed a PCE to improve cognition within the previous year, prompting an increasing number of empirical studies on the effects of PCEs on healthy subjects. The topic has entered public discourse through popular media several times over the last two decades, especially among student populations at highly competitive institutions, like America's Ivy League colleges and Britain's Oxbridge campuses.

Three dimensional (3D) bioprinting is a growing field based on 3D printing technology that is then used with biological materials as 'inks' to construct an expanding variety of materials that are primarily used in medical research. The process requires the creation of a model for the printer, followed by mixing the biological materials in a printer cartridge then printing the object onto the right material, most commonly by building the object layer-by-layer. 3D bioprinting is used today by researchers in pursuit of improving regenerative medicine and also as an educational tool for lessons on biology and/or engineering. Eventually, 3D bioprinters, models, inks and materials may become easily available to the public to create homemade enhancement products, such as plastic components necessary for homemade neurostimulation devices in the short-term or printing home-brewed PCEs in the long-term, to name some possibilities. The medical field may someday use the technology to create replacement organs, such as a liver or heart, for transplant patients.[79] However, there are currently barriers to using 3D-printed organs in patients, such as the possibility of the body rejecting the artificial organ. Once 3D-printed replacement organs become viable, it's possible that modifications could be made to the organs for increased performance, extending the enhancement potential of the

[74] Linssen, op. cit. 2011.
[75] Franke, Andreas G., Patrik Gränsmark, Alexandra Agricola, Kai Schühle, Thilo Rommel, Alexandra Sebastian, Harald E. Balló, et al., "Methylphenidate, modafinil, and caffeine for cognitive enhancement in chess: A double-Blind, randomised controlled trial," *European Neuropsychopharmacology* Vol. 27, No. 3, 2017, pp. 248–260.
[76] Micoulaud, Fond G, "Neuroenhancement in Healthy Adults, Part I: Pharmaceutical Cognitive Enhancement: A Systematic Review," *Journal of Clinical Research & Bioethics* Vol. 06, No. 02, 2015.
[77] Battleday & Brem, op. cit. 2015.
[78] Vagwala, Meghana Kasturi, Aude Bicquelet, Gabija Didziokaite, Ross Coomber, Oonagh Corrigan, and Ilina Singh, "Towards a Moral Ecology of Pharmacological Cognitive Enhancement in British Universities," *Neuroethics* Vol. 10, No. 3, June 2017, pp. 389–403; Schermer, Maartje, Ineke Bolt, Reinoud De Jongh, and Berend Olivier, "The Future of Psychopharmacological Enhancements: Expectations and Policies," *Neuroethics* Vol. 2, No. 2, November 2009, pp. 75–87.
[79] Kang, Hyun-Wook, Sang Jin Lee, In Kap Ko, Carlos Kengla, James J Yoo, and Anthony Atala, "A 3D bioprinting system to produce human-Scale tissue constructs with structural integrity," *Nature Biotechnology* Vol. 34, No. 3, March 2016, pp. 312–322.

technology. Based on our definition of HET, it's not clear that 3D bioprinters themselves are HET, but the objects produced by 3D bioprinters are expected to eventually include HET that better fits our definition.

3.5 Workplace applications

Image & performance-enhancing drugs (IPEDs) may be the most familiar category of HET, as it encompasses drugs commonly discussed in so-called 'doping' scandals in professional sports. IPEDs are heavily regulated in most countries, with off-label enhancement use prohibited to prevent users from harming themselves. Despite safety issues and legal consequences for the illicit use of IPEDs, many individuals choose to accept the risks to increase their physical performance and/or appearance by using IPEDs.

Eventually, safe IPED options may become available: drugs that increase physical performance or image without the negative side-effects found in most modern IPEDs. Existing IPEDs may be prescribed by physicians as therapeutic treatments for conditions such as muscular dystrophy. Research and development of IPEDs is expected to advance first for the benefit of improving these therapies, but may transition to a new R&D subfield if HET becomes an established scientific field.

Head-mounted devices, such as virtual-reality (VR) headsets like the HTC Vive and Oculus Rift or augmented-reality (AR) devices like Microsoft Hololens, have recently begun entering the consumer market. Although many of the immediate uses of such devices are for entertainment, the technology's potential for human enhancement is geared more toward the workplace. For example, architects can use VR headsets to explore their creations prior to construction, enhancing their capacity to complete the design tasks in their jobs. VR devices could also be used in the courtroom to enhance both judges and jurors' cognitive performance and provide for a fair trial.[80] In fact, it was recently reported that VR has already been deployed in a courtroom in China.[81] AR devices could be used in a variety of professions to enhance users' capacity to quickly review relevant information without interfacing with a more cumbersome device. Moreover, HMDs have proven their effectiveness within the medical field both as a training device for medical students performing surgeries[82] and as a cognitive enhancement device, for example enabling anaesthesiologists to focus on both the patient and their vital signs simultaneously during surgeries.[83]

Intelligent personal assistants (IPAs) are machine-based technologies generally consisting of AI designed to help users achieve simple goals such as managing their shopping tasks or maintaining a training regimen. Existing IPAs, such as Amazon's Alexa or Apple's Siri, often utilize speech technologies for verbal interface systems. IPAs may qualify as HET by helping a user to offload simple tasks such as

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[80] Bailenson, Jeremy N., Jim Blascovich, Andrew C. Beall, and Beth Noveck, "Courtroom Applications of Virtual Environments, Immersive Virtual Environments, and Collaborative Virtual Environments," *Law Policy* Vol. 28, No. 2, 2006, pp. 249–270; Bruce, Kaufman, "The Next Frontier for Virtual Reality: Courtrooms," *Big Law Business*, Bloomberg Law, November 18, 2017. https://biglawbusiness.com/the-next-frontier-for-virtual-reality-courtrooms/.

[81] Nafarrete, Jonathon, "Chinese Courtroom Uses VR to Revisit Crime Scene," *VRScout*, VRScout Inc., March 2, 2018. https://vrscout.com/news/chinese-courtroom-vr-crime-scene/.

[82] Rebelo, Francisco, Emília Duarte, Paulo Noriega, and Marcelo Soares, "Virtual Reality in Consumer Product Design," *Human Factors and Ergonomics in Consumer Product Design Ergonomics Design & Mgmt. Theory & Applications*, 2011, pp. 381–402.

[83] Liu, David, Simon A. Jenkins, Penelope M. Sanderson, Perry Fabian, and W. John Russell, "Monitoring with Head-Mounted Displays in General Anesthesia," *Anesthesia & Analgesia* Vol. 110, No. 4, 2010, pp. 1032–1038.

managing schedules to a wearable or mobile device, allowing the user to focus on more challenging tasks. Eventually, future IPAs may provide additional enhancements, perhaps by managing the administration of PCEs or other pharmaceutical enhancement. For more about IPAs, see SIENNA D4.1, *State of the art review of robotics & AI*.

Artificial blood is a medical technology with enhancement potential. Experiments to find blood substitutes, i.e. fluid with the capacity to carry oxygen in the human body in a similar way to biological blood, have a lengthy history. Several medical trials for hemoglobin substitutes have failed over the last decade, though a 2010 study investigating the potential to use stem cells to produce artificial blood cells showed promise.[84] Within the next 10 years, advances in tissue engineering is expected to allow blood vessels created for specific patients.[85] Eventually, artificial blood may be developed to enhance physical performance by functioning better than biological blood.[86]

Radio-frequency identification (RFID) keys are primarily known via their application within contactless payment systems in some debit and credit cards. However, this technology can also be implemented within the human body as a **subdermal RFID key**. These keys are a body-modification in which a user installs an RFID chip beneath their skin, often on their hand, that can then be used with RFID readers in many ways, often as a biometric security measure. RFID keys for authentication and identification processes are already present in the commercial market. For example, an RFID key could be used to unlock a door, turn on the lights in a 'smart' home or office, open an encrypted computer file or enable automatic payment. RFID keys are faster, cheaper and more reliable than traditional biometric technologies. The main advantages lie in the speed of the identification. No time is lost while typing in a password or taking a smart card out of your pocket. Moreover, remembering passwords, cleaning your hands for fingerprint identification or sitting still for an iris scan can be cumbersome in even the best cases. Furthermore, as many biometric applications expire due to changes from ageing, RFID keys are more durable. Downsides include the proven possibility of implanting a virus within an RFID key that can spread to other connected technologies that interface with the keys. Another application which has recently gained interest is the monitoring of medical devices within one's body, such as a heart valve, breast implant or hip replacement via an RFID chip. The RFID chip is embedded within the medical device before it is surgically implanted. Thanks to the RFID technology, the rupture of a breast implant, for example, can easily be detected and communicated to one's physician in a non-invasive manner.[87]

3.6 Military / defence applications

Prosthetics traditionally include any article used to replace a lost or missing human limb, i.e. an artificial arm for a wounded soldier returning from the battlefield after losing their biological arm. The first documented prosthetics come from ancient history, such as an artificial leg dating to about 300

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84 Edwards, Lin, "Artificial blood developed for the battlefield," *Medical Xpress - medical research advances and health news*, Medical Xpress, July 13, 2010. https://medicalxpress.com/news/2010-07-artificial-blood-battlefield.html.
85 Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
86 Frcitas, op. cit. 1998.
87 Gasson, Mark N., "Human ICT Implants: From Restorative Application to Human Enhancement," *Information Technology and Law Series Human ICT Implants: Technical, Legal and Ethical Considerations*, 2012, pp. 11–28; Foster, Kenneth, and Jan Jaeger, "RFID Inside: The Murky Ethics of Implanted Chips," *IEEE Spectrum* Vol. 44, No. 3, 2007, pp. 24–29.

B.C.E. and a Roman general who used an iron hand during the Second Punic War around 215 B.C.E. allowing him to return to battle.[88] The technology for the development of prosthetic limbs had its first real breakthrough during and after World War I. The public debate on the best approach for the design and development of prosthetic limbs on an industrial scale may also have sparked the first public debate on the ethics of HET in the 20th century.[89] Modern prosthetics have advanced significantly, such that the use of 'blade'-style prosthetic legs led to a body of research that continues to evolve regarding whether or not the prosthesis may give amputees an unfair advantage in running or jumping competitions.[90] Experiments are underway to improve functionality by installing AI to enable complex manoeuvres by artificial limbs that were previously impossible.[91] Although it is not yet the case that artificial limbs regularly outperform biological limbs, 3D printing has already enabled amputees to stylize their prostheses to look and theoretically perform differently from biological limbs.[92] Research on HET prosthesis is likely to be driven by the military to equip soldiers with enhanced abilities if they lose their biological limb in the field, or even by able-bodied soldiers wearing exoskeleton, hence including the application under the military/defence category.[93] The impediments to weaponising prostheses today are more ethical than technological; in fact, a tattoo artist recently installed a 'tattoo gun' arm instead of a traditional prosthetic arm to facilitate his ability to perform in his trade, demonstrating in practice that prosthetic limbs need not only function in the same way as biological limbs.[94]

Modern **implanted neural interfaces (INIs)** are almost exclusively found in therapeutic treatments such as deep-brain stimulation (see *neuromodulatory techniques* below) or cochlear implants. Scientific investigation is already underway for additional neural implants to restore vision, motor function and improve memory.[95] However, future neural implants may theoretically enable many new human enhancements, such as a pseudo-telepathic link between users[96], within the next 10 to 20

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[88] Norton, Kim M, "A Brief History of Prosthetics," *Amputee Coalition*, n.d. https://www.amputee-coalition.org/resources/a-brief-history-of-prosthetics/.
[89] Araujo, Marcelo de, "World War I to the Age of the Cyborg: the Surprising History of Prosthetic Limbs," *The Conversation*, The Conversation Trust (UK) Limited , September 6, 2016. https://theconversation.com/world-war-i-to-the-age-of-the-cyborg-the-surprising-history-of-prosthetic-limbs-64451.
[90] Greenemeier, Larry, "Blade Runners: Do High-Tech Prostheses Give Runners an Unfair Advantage?," *Scientific American*, August 5, 2016. https://www.scientificamerican.com/article/blade-runners-do-high-tech-prostheses-give-runners-an-unfair-advantage/.
[91] Powell, Andrea, "AI Is Fueling Smarter Prosthetics Than Ever Before," *Wired*, Conde Nast, December 22, 2017. https://www.wired.com/story/ai-is-fueling-smarter-prosthetics-than-ever-before/.
[92] Swatman, Rachel, "How the first prosthetic arm based on a videogame has transformed a gamers life," *Guinness World Records*, Guinness World Records, December 1, 2017. http://www.guinnessworldrecords.com/news/2017/12/how-the-first-prosthetic-arm-based-on-a-videogame-has-transformed-a-gamers-life-504378.
[93] Reardon, op. cit., 2015; "Full Metal Jacket," *The Economist*, The Economist Newspaper Limited, December 19, 2015. https://www.economist.com/news/science-and-technology/21684117-battlefield-factory-floor-orthopaedic-clinic-artificial; Knefel, John, "How the Pentagon Is Building the Super Soldiers of Tomorrow," *Inverse*, January 7, 2016. https://www.inverse.com/article/9988-how-the-pentagon-is-building-the-enhanced-super-soldiers-of-tomorrow.
[94] Muoio, Danielle, "A French artist has an incredible prosthetic arm that doubles as a tattoo gun," *Business Insider*, Business Insider, June 28, 2016. http://www.businessinsider.com/artists-prosthetic-arm-is-a-tattoo-gun-2016-6?international=true&r=US&IR=T.
[95] Hochberg, Leigh, and Thomas Cochrane, "Implanted Neural Interfaces: Ethics in Treatment and Research," *Neuroethics in Practice*, July 2013, pp. 235–250.
[96] DARPA, "Bridging the Bio-Electronic Divide," *Defense Advanced Research Projects Agency*, n.d. https://www.darpa.mil/news-events/2015-01-19.

years. Military research is already underway for neural-connected BCIs that allow the user to control connected devices via thought, as well as transcranial neuro-stimulation devices that improve reaction time.[97] Although research on INIs is split between private-sector, governmental and academic projects[98], military/defence projects are likely to precede adoption by the public if only due to the perception of risk in undergoing brain surgery. Eventually, INIs may move features, such as searching for information on the internet, from hand-held or desktop devices into the brain.

Hiding from enemies, be they hunters or combatants in war, has been a survival strategy found in nature for millions of years. Progress toward robust **biological camouflage** moved forward in 2014[99] and again in 2017[100] although it remains unclear when the technology may be deployed in real-world circumstances. The current line of research adapts cephalopod camouflage techniques from nature into a synthetic electronic skin that changes colour to simulate the surrounding environment. Although some have noted how the technology could be used for art or fashion[101] or by researchers or other individuals who work with animals that flee when detecting a human presence, the most obvious use would be for military/defence scenarios.

A variety of human enhancement projects are in various stages of research at military institutions, such as material to scale walls or a drug allowing the user to function without sleep for extended periods of time.[102] **Bioweapons** include any military/defence HET otherwise not covered in this chapter. We were unable to find much evidence suggesting HET augmentations have been militarized today, but the range of military HET experiments makes it plausible to consider that some HET may become weaponized in the future. One compelling exception is a report stating modafinil has been administered to helicopter pilots as a cognitive enhancement.[103] The same report also noted that development of HET may enable actors to 'de-enhance,' or degrade, human capacities. Science-fiction abounds with imagined bioweapons, such as 'bioware' augmentations in the *Shadowrun* RPG that range from self-healing armour skin to implantable venom sacs[104], enhanced reflex augmentations in

[97] The Economist, "How to Make Soldiers' Brains Better at Noticing Threats," *The Economist*, The Economist Newspaper, July 27, 2017. https://www.economist.com/news/science-and-technology/21725543-target-recognition-warfare-how-make-soldiers-brains-better-noticing; The Economist, "Using Thought to Control Machines," *The Economist*, The Economist Newspaper, January 4, 2018. https://www.economist.com/news/leaders/21733983-brain-computer-interfaces-may-change-what-it-means-be-human-using-thought-control-machines.
[98] Gent, Edd, "Brain-Computer interfaces are coming: Consensual telepathy, anyone?," *The Washington Post*, WP Company, June 11, 2017. https://www.washingtonpost.com/national/health-science/brain-computer-interfaces-are-coming-consensual-telepathy-anyone/2017/06/09/9345c682-46ef-11e7-98cd-af64b4fe2dfc_story.html?utm_term=.ed3924c6dced.
[99] Yu, C., Y. Li, X. Zhang, X. Huang, V. Malyarchuk, S. Wang, Y. Shi, et al., "Adaptive optoelectronic camouflage systems with designs inspired by cephalopod skins," *Proceedings of the National Academy of Sciences* Vol. 111, No. 36, 2014, pp. 12998–13003.
[100] Pikul, J. H., S. Li, H. Bai, R. T. Hanlon, I. Cohen, and R. F. Shepherd, "Stretchable surfaces with programmable 3D texture morphing for synthetic camouflaging skins," *Science* Vol. 358, No. 6360, December 2017, pp. 210–214.
[101] Choi, Charles Q., "The Octopus-Inspired Adaptive Camouflage," *Popular Mechanics*, Popular Mechanics, November 14, 2017. https://www.popularmechanics.com/science/animals/a11105/behold-the-octopus-inspired-adaptive-camouflage-17108661/.
[102] DARPA, "Our Research Archive," *Defense Advanced Research Projects Agency*, n.d. https://www.darpa.mil/archive/our-research.
[103] The Royal Society, Brain waves module 3: Neuroscience, conflict, and security. London: Science Policy Centre, 2012. https://royalsociety.org/~/media/Royal_Society_Content/policy/projects/brain-waves/2012-02-06-BW3.pdf
[104] Weisman, Jordan, *Shadowrun*, FASA, Chicago, IL, 1998.

The Expanse novels[105], or 'wet-wired' implants such as personal force fields, scanners and projectile weapons in the *Commonwealth*[106] novels, just to name a few. Although the likelihood of such science-fiction enhancements becoming a reality within the next 20 years remains slim, in theory less-robust bioweapons could enter research stages in the near future, making the application area an important consideration as the wider field of HET advances. In fact, there is evidence that a highly addictive substance called 'Captagon' has been used as a cognitive enhancer in the ongoing conflict in Syria similar to the use of Pervitin and Benzadrine in World War II and modafinil in more recent engagements, reminding the world that military actions have a tendency to drive technologies such as HET forward.[107]

3.7 Home or recreation applications

A number of **neuromodulatory techniques** have been developed that have enhancement potential. Transcranial direct-current stimulation (tDCS) devices run a small and constant electrical current through the skull to alter the behaviour of neurons in the brain. tDCS is often used as a treatment for depression, pain relief, or to reduce the cravings of addicts. The efficacy of tDCS for enhancement has faced skepticism recently[108], although results have found tDCS can improve language and numerical learning[109] and sport performance.[110] tDCS is one of the least-invasive neurostimulation methods, which has led to the emergence of a growing market of consumer devices that may overstate the technique's enhancement potential. For example, Thync uses tDCS alongside TENS (transcutaneous electrical nerve stimulation) to help the user control their mood.[111] The Foc.us is a standalone device that can be linked to a computer or smartphone which can provide tDCS along with a number of other neurostimulation techniques like cranial electrotherapy stimulation (CES). Another company has introduced a device called Halo that is reported to enhance athletes' reaction time.[112] In addition to consumer products, a Do-It-Yourself (DIY) 'brain-hacking' community has emerged, consisting of individuals who construct home-built tDCS devices.[113]

Transcranial magnetic stimulation, or TMS, is another non-invasive neuromodulatory technique similar to tDCS. Whereas tDCS utilizes electrical currents to modulate neural activity, TMS works via a

[105] Corey, James S. A., *Abaddons gate*, Orbit, an imprint of Hatchette Book Group, New York, NY, 2014.
[106] Hamilton, Peter F., *Pandoras star.*, 2004.
[107] Kalin, Stephen, "Insight - War Turns Syria into Major Amphetamines Producer, Consumer," *Reuters*, Thomson Reuters, January 13, 2014. https://uk.reuters.com/article/uk-syria-crisis-drugs/insight-war-turns-syria-into-major-amphetamines-producer-consumer-idUKBREA0B04K20140113.
[108] Horvath, Jared Cooney, Jason D. Forte, and Olivia Carter, "Quantitative Review Finds No Evidence of Cognitive Effects in Healthy Populations From Single-Session Transcranial Direct Current Stimulation (TDCS)," *Brain Stimulation* Vol. 8, No. 3, 2015, pp. 535–550.
[109] Jwa, Anita, "Early adopters of the magical thinking cap: a study on do-It-Yourself (DIY) transcranial direct current stimulation (TDCS) user community," *Journal of Law and the Biosciences* Vol. 2, No. 2, February 2015, pp. 292–335.
[110] Zhu, Frank F., Andrew Y. Yeung, Jamie M. Poolton, Tatia M.c. Lee, Gilberto K.k. Leung, and Rich S.w. Masters, "Cathodal Transcranial Direct Current Stimulation Over Left Dorsolateral Prefrontal Cortex Area Promotes Implicit Motor Learning in a Golf Putting Task," *Brain Stimulation* Vol. 8, No. 4, 2015, pp. 784–786.
[111] Brenninkmeijer, Jonna, and Hub Zwart, "From 'Hard' Neuro-Tools to 'Soft' Neuro-Toys? Refocusing the Neuro-Enhancement Debate," *Neuroethics* Vol. 10, No. 3, February 2016, pp. 337–348.
[112] Orcutt, Mike, "These Headphones Will Zap Your Brain," *MIT Technology Review*, MIT Technology Review, August 4, 2016. https://www.technologyreview.com/s/601054/brain-zapping-headphones-could-make-you-a-better-athlete/.
[113] HCE Wiki, "Transcranial direct-Current stimulation," *The Human Cognitive Enhancement Wiki*, n.d. http://hcewiki.zcu.cz/hcewiki/index.php/Transcranial_direct-current_stimulation.

magnetic strip placed on the brain that creates a magnetic field to modulate neural activity[114]. Repetitive use of the technique, or rTMS, is used for treating clinical depression, a number of physiological disorders such as Parkinson's disease[115] and migraines.[116] TMS is thought to have potential as a cognitive enhancement technique, though some of the most recent literature has cast scepticism on the likelihood of the technique improving anything other than working memory, and even this has not been proven in healthy subjects.[117]

Deep brain stimulation, or DBS, is a third neurostimulation technique, although unlike tDCS and TMS, DBS is considerably more invasive. DBS requires surgery to insert an electrode into a patient's brain. Even so, DBS is an increasingly accepted treatment for several severe neuropsychiatric disorders, such as Parkinson's disease and migraines, among others. One study reported an increase to a patient's memory for DBS used to correct obesity by stimulating the hypothalamus, a part of the brain known to have a link to memory.[118] As long as DBS requires invasive surgery, its enhancement potential will remain limited, although knowledge gained from research via the technique may prove useful for other applications.

Wearables are computational technologies that a user can utilize to interface in a variety of ways with other devices, services, or technologies. For example, a smart watch, in addition to telling the time, can also take biometric readings to monitor a user's health or daily exercise. Data from wearable devices can further integrate with IPAs such as by helping a user to follow a training regimen. Devices from Neurowear, such as the Necomimi and Shippo, utilize EEG to control accessories designed to communicate the user's mood to the public.[119] Some neurostimulation devices may also be considered a wearable depending on how mobile the device is.

Cosmetic surgery is one of the few widely-available non-therapeutic enhancements today. Some cosmetic surgeries are performed for therapy, but many healthy subjects choose to undergo elective cosmetic surgery with no clinical therapeutic benefits. Even if a cosmetic surgery is conducted for ostensibly therapeutic reasons, unless it is used to remedy the effects of an injury or disease it fails to meet the necessary conditions of a restorative treatment.[120] Plastic surgery, i.e. cosmetic surgery that alters the appearance of the patient often using synthetic materials, was first developed as a treatment for disfigured soldiers' faces during World War I. Since then, a variety of additional cosmetic surgeries have become available to the public, such as hair replacement surgery, cosmetic dental procedures to

[114] Eldaief, M. C., D. Z. Press, and A. Pascual-Leone, "Transcranial magnetic stimulation in neurology: A review of established and prospective applications," *Neurology*: Clinical Practice Vol. 3, No. 6, 2013, pp. 519–526.
[115] Lefaucheur, Jean-Pascal, Nathalie André-Obadia, Andrea Antal, Samar S. Ayache, Chris Baeken, David H. Benninger, Roberto M. Cantello, et al., "Evidence-Based guidelines on the therapeutic use of repetitive transcranial magnetic stimulation (RTMS)," *Clinical Neurophysiology* Vol. 125, No. 11, 2014, pp. 2150–2206.
[116] Lipton, Richard B, David W Dodick, Stephen D Silberstein, Joel R Saper, Sheena K Aurora, Starr H Pearlman, Robert E Fischell, Patricia L Ruppel, and Peter J Goadsby, "Single-Pulse transcranial magnetic stimulation for acute treatment of migraine with aura: a randomised, double-Blind, parallel-Group, sham-Controlled trial," *The Lancet Neurology* Vol. 9, No. 4, 2010, pp. 373–380.
[117] Martin, Donel M., Shawn M. Mcclintock, Jane Forster, and Colleen K. Loo, "Does Therapeutic Repetitive Transcranial Magnetic Stimulation Cause Cognitive Enhancing Effects in Patients with Neuropsychiatric Conditions? A Systematic Review and Meta-Analysis of Randomised Controlled Trials," *Neuropsychology Review* Vol. 26, No. 3, 2016, pp. 295–309.
[118] Hamani, Clement, Mary Pat Mcandrews, Melanie Cohn, Michael Oh, Dominik Zumsteg, Colin M. Shapiro, Richard A. Wennberg, and Andres M. Lozano, "Memory enhancement induced by hypothalamic/Fornix deep brain stimulation," *Annals of Neurology* Vol. 63, No. 1, 2008, pp. 119–123.
[119] Brenninkmeijer & Zwart, op. cit. 2016.
[120] Coenen, et. al., op. cit., 2009, p18.

improve a patient's smile and skin/lip filters. A recent Pew survey on HET conducted in the United States found a majority of Americans view modern cosmetic enhancements as an 'appropriate use of technology.'[121] Although we have placed this category of HET under home or recreation applications, many individuals choose to undergo elective cosmetic enhancement surgeries to gain an edge in the workplace, i.e. by subjectively improving their appearance with the intention of enhancing the opinion of their appearance from their clients.

Laser eye surgery is typically classified as an elective, cosmetic procedure because it is often used to enhance one's natural vision, though the technique is also used to correct poor or damaged eyesight. As with other cosmetic surgeries, laser eye surgery was initially developed as a treatment but later was found to have the potential to enhance vision for healthy persons as well.

Body modifications involve augmenting part of a healthy body to introduce new capabilities, achieve a personal aesthetic goal and/or improve performance. Existing body modifications include, but are not necessarily limited to, magnetic implants[122], cyborg antenna[123] or eyes[124], tattoos and piercings. Although most modern body modification is aesthetic, the increasing number of implant-based modifications that add or improve capabilities suggests the application may expand as a wide category for HET in the future. For example, Neil Harbisson's 'eyeborg' antenna allows him to experience colour as sound.

Sex enhancement, like cosmetic surgery, is also among the few widely-available non-therapeutic enhancement options available today, and, once again, is sometimes performed for therapeutic reasons but may also be undertaken as an enhancement option with no clinical therapeutic value. Modern sex enhancements include reproductive surgeries such as vasectomy or tubal ligation procedures to remove one's procreative capability, contraception, sex reassignment surgeries, sex selection and some cosmetic surgeries. In Pew's 2016 survey, a majority of Americans identified 'surgeries to prevent having children'[125] as an appropriate use of technology. Female genital cosmetic surgery (FGCS) aims at modifying the body in order to enhance sexual pleasure either physically or indirectly by increasing the confidence of the patient. Due to a regression of negative associations together with a positive approach to sexual pleasure in many wealthy societies, the popularity of this branch of cosmetic surgery has increased tremendously. Cosmetic genital alterations aim to create a 'designer vagina' and include the reduction of the labia minora, fat injections or tissue removal of the

[121] Funk, Cary, Brian Kennedy, and Elizabeth Podrebarac Sciupac, "U.S. Public Wary of Biomedical Technologies to 'Enhance' Human Abilities," *Pew Research Center: Internet, Science & Tech*, July 26, 2016. http://www.pewinternet.org/2016/07/26/u-s-public-wary-of-biomedical-technologies-to-enhance-human-abilities/.

[122] Hameed, Jawish, Ian Harrison, Mark N. Gasson, and Kevin Warwick, "A novel human-Machine interface using subdermal magnetic implants," *2010 IEEE 9th International Conference on Cybernetic Intelligent Systems*, 2010.

[123] Jeffries, Stuart, "Neil Harbisson: the world's first cyborg artist," *The Guardian*, Guardian News and Media, May 6, 2014. https://www.theguardian.com/artanddesign/2014/may/06/neil-harbisson-worlds-first-cyborg-artist.

[124] Caughill, Patrick, "Meet the Eyeborg: The Filmmaker With a Video Camera In His Right Eye Socket," *Futurism*, June 15, 2017. https://futurism.com/meet-the-eyeborg-the-filmmaker-with-a-video-camera-in-his-right-eye-socket/.

[125] Funk, Cary, Brian Kennedy, and Elizabeth Podrebarac Sciupac, op. cit., 2016.

labia majora, liposuction, vaginal tightening, G-spot amplification, clitoral repositioning and restoring the appearance of virginity.[126]

While many see sex selection as immoral, others argue that selecting the sex of one's unborn baby lies upon the same grounds of one's liberty to control their number of offspring by contraception or reproductive surgeries.[127] The generally longer life expectancy of women makes sex selection an interesting tool for welfare or moral enhancement. However, this notion is sometimes criticised under the guise of male elimination, therefore must not be confused with reducing polygamy-related dimorphic traits.[128] The scientific progress in reprogramming stem cells into different kinds of tissue has opened new doors for sex reassignments, promising the ability to create a fully functioning transgender body by 2024. Earlier breakthroughs include transforming adult ovaries into testes and lab-grown fully functioning vaginas.[129]

	Healthcare	Education	Workplace	Military	Home
Cognitive	Propranolol (memory)*	Methylphenidate (focus)*	Methyphenidate (focus)*	Modafinil (wakefulness)*	Neurostim-ulation*
Affective	SSRIs*	Engagement enhancer	Boredom reducer	Fear reducer	Happiness enhancer
Moral	Chemical castration*	Cooperation enhancer	Methylphenidate (to curb recidivism)*	Robust moral enhancement intervention	Empathy enhancer
Physical	IPED*	Intelligent personal assistant*	Advanced prosthetics	Prosthetics*	Wearables*
Cosmetic	Plastic surgery*	Aesthetic body-modification	Subdermal RFID key*	Biological camouflage	Plastic surgery*
Longevity	Aging-process reducer	Common cold vaccine	Zero-gravity coping enhancement	Synthetic skin replacement	Memory backup

Table 8: Examples of existing & expected enhancements by domain (* denotes existing application)

[126] Braun, Virginia, "In Search of (Better) Sexual Pleasure: Female Genital 'Cosmetic' Surgery," *Sexualities* Vol. 8, No. 4, 2005, pp. 407–424; Goodman, Michael P., "Female Genital Cosmetic and Plastic Surgery: A Review," *The Journal of Sexual Medicine* Vol. 8, No. 6, 2011, pp. 1813–1825.
[127] McCarthy, David, "Why Sex Selection Should Be Legal," *Journal of Medical Ethics* Vol. 27, No. 5, January 2001, pp. 302–307.
[128] Casal, Paula, "Sexual Dimorphism and Human Enhancement," *Journal of Medical Ethics* Vol. 39, No. 12, August 2012, pp. 722–728.
[129] Uhlenhaut, N. Henriette, Susanne Jakob, Katrin Anlag, Tobias Eisenberger, Ryohei Sekido, Jana Kress, Anna-Corina Treier, et al., "Somatic Sex Reprogramming of Adult Ovaries to Testes by FOXL2 Ablation," *Cell* Vol. 139, No. 6, 2009, pp. 1130–1142; Ice, Valkyrie, "Best of H+: Total Gender Change within a Decade," *h+ Media*, Humanity+ , May 8, 2014. http://hplusmagazine.com/2014/05/08/total-gender-change-within-decade/; Taylor, Victoria, "Woman with Lab-Grown Vagina: 'I Have a Normal Life'," *NY Daily News*, New York Daily News, April 19, 2014. http://www.nydailynews.com/life-style/health/woman-lab-grown-vagina-normal-life-article-1.1761999.

4. Socio-economic impact assessment

4.1 Introduction

This chapter documents the approach for and findings of the socio-economic impact assessment (SEIA) for human enhancement technologies (HETs).

We define SEIA as a systematic analysis used to identify and assess the socio-economic impacts of HETs on society. Impacts refer to the potential changes caused – directly or indirectly, in whole or in part, for better or for worse – by the technologies under consideration. As required by the *SIENNA Description of Action,* this exercise covers current and future social, economic and environmental impacts. A SEIA has many benefits. For example, it

- helps identify and distinguish numerous impacts;
- assists parties to address significant and adverse impacts;
- finds ways to reduce, remove or prevent these impacts from happening;
- builds trust with consulted stakeholders;
- provides a dialogue platform or springboard for planning how to maximise the beneficial impacts via appropriate policies and regulations.

Next, we discuss the objectives and scope of the SIENNA SEIA. Section 4.2 discusses the approach and methodology for the wider SEIA. Section 4.3 presents the results of the HETs impact identification. Section 4.4 presents the results of the assessment (direction of impacts, significance, timelines, affected parties, geographical reach, whether impacts support or undermine affected communities and their societal values, resilience and vulnerability of potentially affected communities, potential for unmanageable change, costs of the impacts, mitigation measures). Section 4.5 consists of an investigation of impacts based on affected parties and also identifies further risks. Section 4.6 concludes the SEIA.

Objectives and scope

The objective of this SEIA is to identify and assess current and expected social, economic, and environmental impacts of HET. As stated before, SIENNA defines 'human enhancement' as a modification aimed at improving human performance and brought about by science-based and/or technology-based interventions in or on the human body.

The scope of this SEIA is limited and not equal to that carried out in SIENNA for AI and robotics or genomics. Factors influencing this include the broad nature of the subject, the development of HETs and their applications, and the resources available for the conduct of the SEIA.

There are various types of social, economic, and environmental impacts, e.g., as outlined in the European Commission (EC) *Impact Assessment Guidelines*[130]:

- **Social impacts** include impacts on employment and labour markets, standards and rights related to job quality, social inclusion and protection of particular groups, gender equality, equal treatment and opportunities, non-discrimination, individuals' private and family life, personal data, governance, participation, good administration, access to justice, media and

[130] For detailed information and precise questions see: European Commission, *Impact Assessment Guidelines*, 15 January 2009. http://ec.europa.eu/smart-regulation/impact/commission_guidelines/docs/iag_2009_en.pdf

ethics, public health and safety, crime, terrorism and security, access to and effects on social protection, health and educational systems, culture, and social impacts in third countries.[131]

- **Economic impacts** include impacts on the functioning of the internal market and competition, competitiveness, trade and investment flows, operating costs and conduct of business, small and medium enterprises, administrative burdens on businesses, public authorities, property rights, innovation and research, consumers and households, specific regions or sectors macroeconomic environment, third countries and international relations.
- **Environmental impacts** include impacts on the climate, transport and the use of energy, air quality, biodiversity, flora, fauna and landscapes, water quality and resources, soil quality or resources, land use, renewable or non-renewable resource use, environmental consequences of firms and consumers, waste production, generation and recycling, the likelihood or scale of environmental risks, animal welfare and international environmental impacts.

The EC Guidelines present a wide variety of impact assessment categories, not all of which may be relevant to our assessment of the impacts of HETs. These categories guided the HET SEIA perspective, and the identification of impacts used these categories as guidance in determining what types of impacts have already been identified, the gaps that exist and future issues.

4.2 Approach and methodology for the SEIA

The SIENNA HET SEIA involved the following key steps:

Figure 2: Steps in the SIENNA HET SEIA

Planning involved composing the team, setting out resources, timelines and approach, including developing supporting materials (e.g., impacts data collection spreadsheet).

The **identification of impacts** was carried out via a literature survey identifying current and past studies, policy and other documents that have analysed social, economic and environmental impacts of HETs.

The team evaluated and **assessed the impacts** identified based on key criteria (outlined further below).

A mini survey[132] was carried out from 5 February 2018 to 12 February 2018 to assess the significance of socio-economic impacts of HETs, i.e., to determine the significance of the socio-economic impacts of HETs by examining their likelihood of occurring and their severity. The mini survey was issued to human enhancement experts in academia, industry, civil society, media representatives (identified in

[131] In the EU context, refers to countries that are not a member of the Union.

[132] SIENNA - assessing impacts of human enhancement technologies, mini survey. 2018. https://docs.google.com/forms/d/1DARVRK_zHVM6XPY6KUnzGlvnueQmu9_6U0FYCn16_eM/viewform?edit_requested=true#responses

SIENNA *Task 1.4 Stakeholder analysis*) and shared via social media (SIENNA and of partner institutions). Finally, we identified potential impact mitigation measures and present some **recommendations**.

Trilateral prepared a preliminary report and circulated it to the SIENNA project partners for their feedback and input, after which the impact assessment was revised and finalised.

4.3 Identification of impacts

The goal was to carry out as comprehensive a review as possible to identify impacts in the relevant categories. This was done using online databases such as academic studies, industry, policy and media reports, the social science research network (SSRN), Springer, ScienceDirect, institutional and web repositories such as OpenAire and web search tools (e.g., Bing, Google). Examples of search terms used include:

Search term examples
benefits/advantages [human enhancement technology/cognitive enhancement/physical enhancement/biohacking]
consequences of human enhancement technology
economic impact/implications [human enhancement technology]
environment impact/implications [human enhancement technology]
expectations for human enhancement technology
high-tech human enhancement impacts
human body hacking/engineering impact
human enhancement tech climate change
human enhancement technology impact climate/biodiversity
human technological augmentation
impact assessment [human enhancement technology]
impact of [human enhancement technology/cognitive enhancement/physical enhancement/effective enhancement and moral enhancement]
negative impacts/implications/dangers/adverse consequences [human enhancement technology/cognitive enhancement/physical enhancement]
off-label human enhancement use impacts
risks of human enhancement technology
social impact/implications [human enhancement technology/cognitive enhancement/physical enhancement]

Table 9: Search terms for SEIA

Trilateral carried out the identification of impacts from December 2017 to January 2018.

Limitations and challenges in impact identification

This SEIA faced some challenges and limitations.

There is a paucity of systematic coverage of the impacts of human enhancement. To address this, we broadened our literature search beyond peer-reviewed journal articles and books to include industry reports, working papers (e.g., unpublished draft documents and conference papers) and media accounts. In so doing, we increased the number of literature results, accepting that the accuracy of various publications required even greater scrutiny and consideration.

Human enhancement itself is a fuzzy topic, and the subject matter is not easily demarcated. For instance, there is an unclear boundary between treatment interventions and enhancement. Recognising that debating and delimiting the terminological and conceptual boundaries of human enhancement fall outside the scope of this SEIA, we adopted the definition of human enhancement provided earlier. Our selection of literature relied on this to help confirm the relevance of publications; nevertheless, we acknowledge that the topic and subject matter remain actively debated even though we consistently used a single definition throughout this SEIA.

It was a challenge to identify experts in the field, especially scientists. This challenge is one we present here to highlight it generally. However, the identification of such experts was not part of this SEIA, but rather accomplished during a different SIENNA task – Task 1.4, *Stakeholder analysis*. Using contacts collected during that task, the mini survey[133] created for this SEIA was issued to a variety of experts via e-mail (and openly advertised via Twitter[134] and blog posts[135]) in HETs. Still, the general challenge remains, which we acknowledge.

Dijkstra and Schuijff highlight another issue, which is that the 'public's view of human enhancement has not been assessed enough', and that the studies that exist originate mainly from western-oriented countries and cover a wide range of enhancement technologies.[136] It is not within the scope of this SEIA to assess the public's view of human enhancement; this will be achieved via the SIENNA's public opinion surveys and citizen panels.

Based on our literature review, we identified the following social, economic and environmental impacts of HETs.

Social impacts

The social impacts of HETS are wide-ranging and varied. Such impacts relate to society in general, specific groups, and the individual.

[133] https://docs.google.com/forms/d/1DARVRK_zHVM6XPY6KUnzGIvnueQmu9_6U0FYCn16_eM/viewform?edit_requested=true#responses
[134] SiennaEthics. https://twitter.com/SiennaEthics/status/960816081534443520
[135] Trilateral Research, "What Impact will new technoloigies have on our lives? Job losses or new opportunities?" 5 Feb 2018. http://trilateralresearch.co.uk/impact-will-new-technologies-lives-job-losses-new-opportunities/
[136] Dijkstra, A.M., and M. Schuijff, "Public opinions about human enhancement can enhance the expert-only debate: a review study", *Public understanding of science*, Vol. 25, No. 5, 2016, pp. 588-602.

The figure below illustrates the variety of social impacts HETs cause or might have the propensity to cause.

Social impacts of HETs	Alter human capability
	Advance/harm human health
	Affect human psychology
	Affect bodily integrity
	Improve individual abilities
	Create/mitigate social inequalities
	Increase technological reliance
	Change perception of 'human'/way of being
	Affect human freedom and autonomy
	Change personal status and interpersonal relations
	Change freedom of choice and cultures of disabled people
	Transform workplaces
	Increase competition between humans
	Disrupt society
	Promote/reduce unfairness and injustice
	Increase surveillance
	Cause social resistance
	Facilitate ostracisation (of unenhanced, sceptics)

Figure 3: Social impacts of HETs

The social impacts of HETs manifest as impacts upon the individual (e.g., alteration or improvement of one's abilities, positive or adverse impact on their health), groups (e.g., creation of social inequalities, social resistance) and society in general (e.g., increase in technological reliance). These impacts will be analysed further in the following section.

Economic impacts

Our research also identified several economic impacts of HETs. The figure below illustrates these.

Economic impacts of HETs	Increase community wealth
	Burden existing resources
	Oversaturate the market
	Increase unemployment
	Affect international trade relations (HET arms race)
	Perpetuate economic inequalities
	Severely affect developing and least developing countries - high costs, inaccessibility

Figure 4: Economic impacts of HETs

The economic impacts also manifest as impacts upon the individual (e.g., increase in unemployment) groups (e.g., economic inequalities) and society in general (e.g., burden on existing resources). These impacts will be analysed further in the following section.

Environmental impacts

Though it may not be obvious, HETs might also have various environmental impacts that are important to consider. These are presented below:

Environmental impacts	Help adapt to climate change (via biomedical human modifications)
	Degrade the environment
	Increase pressure on environment - HETs waste
	Increase in human-animal resources competition for natural resources
	Impact on animal welfare and testing

Figure 5: Environmental impacts of HETs

The environmental impacts (which are much less discussed in prevalent literature) also manifest as impacts upon the individual (e.g., changes in human ability via biomedical human modifications), animals (e.g., impact on welfare), and society in general (e.g., increase in pressure on the environment).

The next section assesses the impacts of these HETs.

4.4 Assessment of the impacts of HET

This section assesses the impacts of HETs identified in the previous section. It aims to answer questions such as: What is the direction of the identified impacts? What is their significance (determined vis-a-vis their likelihood of occurring and severity)? Who are the affected parties? What is the geographical reach of the impacts? Will the impacts support or undermine affected communities and their values? How resilient are the potentially affected communities? How vulnerable are they to the adverse impacts? Will the impacts cause unmanageable change? What will be the costs of the impacts (and who will bear such costs)? What are the mitigation measures to deal with adverse impacts?

Direction of the impacts

When we look at the **social impacts** identified in section 4, HETs seem to have the potential to bring great benefit for individuals and society, especially for individuals whose health or well-being presents them with challenges. This depends on whether such individuals have access to or can afford HETs.

The figure below explores and summarises the direction of the social impacts of HETs.

Positive

- Improve human capability
- Advance human health and well-being: longer lifespans and expectancy
- Enhance bodily integrity (stop/reduce effects of disease/disability)
- Improve individual abilities and inventiveness
- Mitigate social inequalities
- Reduce unfairness and injustice

Positive and negative

- Alter human capability
- Affect human psychology
- Increase technological reliance
- Change perception of 'human'/way of being
- Change personal status and interpersonal relations
- Change freedom of choice and cultures of disabled people
- Transform workplaces
- Shift towards 'enhanced' society

Negative

- Harm human health (health risks, addiction to HETs, increase in hacking threats to the body)
- Compel individuals to remove or change 'abnormal' or 'unenhanced' traits
- Cause resentment between enhanced and unenhanced people
- Create social inequalities (elites of enhanced, perpetuate social divisions)
- Diminish/damage human freedom, autonomy and bodily integrity
- Increase competition between humans
- Disrupt society (particularly vulnerable populations)
- Homogenise society leading to loss in diversity
- Promote unfairness and injustice
- Increase surveillance (monitoring of individuals)
- Facilitate ostracisation of unenhanced or sceptics
- Give pharmaceutical industries an unprecedented power over human bodies
- Increase risks related to an increased reliance on technology generating an increased vulnerability in case of technological failure

Figure 6: Direction of HET social impacts

Some identified social impacts might have either a positive or negative impact or both. An increased reliance on technology might boost the economy and trade, transform workplaces and lessen human dependency on the one hand, while on the other it might have the adverse effect of making the workers replaced by such technologies redundant. Similarly, HETs have changed (or will change) the perception of what makes us human. While this is good in terms of acceptance in society of enhanced individuals (e.g., disabled people), it might cause harm when unenhanced humans are, or come to be viewed as ‘not normal’, ‘sub-normal’ or ‘not making the grade’. Similarly, the personal status of enhanced individuals might benefit if their enhancements bring them reputational, health or financial rewards while unenhanced individuals might not have similar gains. Thus, the impact on human life could be both positive and negative – even in terms of freedom and way of being.

The shift towards an enhanced society might be positive when it is underpinned by free choice, fairness, distributive justice, transparency etc. Free choice might manifest when individuals use HETs of their own free will or an optional basis, are not obliged to, or coerced into making enhancement choices due to expectations or requirements imposed on them. Fairness would relate to promotion of more equal distribution of abilities via HETs or designing HETs or implementing them in a way that 'levels the playing field'. Distributive justice will involve considering aspects such as income, wealth, opportunities, jobs, welfare, utility, nature of the recipients of HETs (individual persons, groups of persons, reference classes, etc.) and the basis the distribution should be made (equality, maximisation, according to individual characteristics, according to free transactions, etc.).[137] Transparency relates not only to openly discussing HETs impacts but also transparency in their design, development and use.

HETs may have adverse impacts on human health and well-being (e.g., via addiction to HETs, mental health problems, diminished autonomy), society (i.e., via further stratifications in populations, social resistance) and societal values (i.e., via promoting inequality, injustice, unfairness). For vulnerable populations with and without (or with unequal[138]) access to HETs, the ramifications will be greater. For example, there might be greater benefits for cognitively enhanced children than for non-cognitively enhanced children. What might aggravate the negative effects are ineffective legislation to protect against such effects and harmful public policies or policies that do not take such effects into account.

Regarding **the economic impacts**, HETs present opportunities to increase community wealth, promote economic growth and business opportunities via further development in the healthcare sector. Our impact identification exercise also shows that HETs will potentially create additional burdens on society especially economies (and countries) that do not (for various reasons including cultural and religious) or cannot afford to invest in such technologies.

POSITIVE	POSITIVE AND NEGATIVE	NEGATIVE
• Increase community wealth • Promote innovation and economic growth (especially for healthcare providers) • Promote business opportunities	• Affect international trade relations	• Burden existing resources due to longer lifespans • Oversaturate the market • Increase unemployment • Cause/perpetuate a HET arms race • Perpetuate economic inequalities (consumers who can and cannot afford HETs) • Severely affect developing and least developing countries - high costs of, inaccessibility to HETs • Introduce new, more lethal forms of warfare, with severe economic implications.

Figure 7: Direction of economic impacts

[137] Stanford Encyclopedia of Philosophy, "Distributive justice', 22 September 1996 (revised 2017). https://plato.stanford.edu/entries/justice-distributive/
[138] Stupple-Harris, Louis, *Public attitudes to human enhancement*, Sciencewise report, Version 1.0, 2 April 2015.

The **environmental impacts** could be either positive or negative depending on their specific application. A big concern here is that HETs might contribute to some environmental degradation through generation of greater technological waste. This does not mean that HETs may represent a greater threat than any other technologies though it could exacerbate the problem.

POSITIVE	POSITIVE AND NEGATIVE	NEGATIVE
• Help adapt to climate change (via biomedical/technological modification of human beings)	• Help adapt to climate change (via biomedical human modifications)	• Degrade the environment - HETs waste and toxicity • Increase pressure on environment • Increase competition between humans and animals for natural resources • Impact on animal welfare vis a vis increase in testing of HETs

Figure 8: Direction of environmental impacts

Significance of the impacts: mini survey results

HETs have great potential to disrupt society, and this seems likely to happen given the advances in the state of art. To get a better picture and based on our initial identification of impacts, Trilateral carried out a mini survey to assess the significance of some socio-economic impacts of human enhancement technologies (HETs) – this was mainly done by looking at the likelihood and severity of selected impacts. This section documents these results.

The mini survey when tested took under 15 minutes to complete. Respondents did not need to sign in, and the survey did not collect any personal data. The only two types of information collected were type of stakeholder and country. The anonymised raw research data will be archived in the SIENNA institutional repository to make it available to other SIENNA researchers in line with current data-sharing practices. Participation was entirely voluntary, and participants could withdraw at any time.

In the mini survey, we defined 'impact' as a change – positive and/or negative, direct or indirect, in whole or in part – caused by or associated with human enhancement technologies. 'Likelihood' was defined as a chance that something might happen and 'severity' as the gravity or seriousness of the impact. In creating the survey, we used the 4x4 evaluation scale based on the likelihood of the impact occurring and then the severity of the impact. i.e.,

Likelihood of Impact	Severity of Impact
1. Improbable	1. No impact
2. Unlikely	2. Minor
3. Likely	3. Moderate
4. Certain	4. Severe

Table 10: Mini-survey scale

The mini survey had 15 questions (including multiple choice and open ended – see Annex 1).

28 people completed the mini survey.[139] Out of these 15 classified themselves as academics, 5 as individuals, 3 as industry, 2 as civil society, 1 regulator, 1 media, 1 member of an ethics committee. The countries represented were: Argentina (1), Australia (1), Brazil (9), France (1), Germany (1), Greece (1), India (1), Ireland (1), Italy (2), Netherlands (2), Romania (1), Spain (1) Sweden (3) and UK (3).

We acknowledge the limitations of the mini survey's small sample size (e.g., voluntary response bias[140]). The results have not been tested for statistical significance (p-value); this mini survey was meant to help quickly illustrate views on the topic, enhance the analysis and help us determine what might be the significance of the impacts. The advantages of this mini survey were that it was inexpensive[141] to conduct, helped us to reach out to a variety of interested stakeholders through open invitation by e-mail and social media, was flexible to the SEIA's needs and provided us with quick results (due to its fast turn-around time)[142] that we can reflect upon and use as we move forward with the project. We anticipate more rigorous empirical results from the SIENNA public opinion surveys and citizen panels that will be conducted later in the project.

The table below presents the views of the mini survey respondents on the likelihood and severity of the impacts and assesses their potential significance on a scale of high to low. A more detailed analysis of the responses to each of these questions is documented in *Annex 2 (Responses on likelihood and severity).*

Impact *(listed in the order administered in mini survey)*	Likelihood (majority view)	Severity (majority view)	Potential significance (low, medium, high)[143]
Increase in reliance on technology	Certain (17.9%) **Likely (71.4%)** Unlikely (7.4%) Improbable (3.7%)	Severe (40.7%) **Moderate (51.9%)** Minor (7.4%)	High
Creation and/or increase in social inequalities	Certain (21.4%) **Likely (71.4%)** Unlikely (3.6%) Improbable (3.6%)	**Severe (46.4%)** Moderate (42.9%) Minor (7.1%) No impact (3.6%)	High
Change in the perception of what makes us human	Certain (3.6%) **Likely (67.9%)** Unlikely (21.4%) Improbable (7.1%)	Severe (28.6%) **Moderate (39.3%)** Minor (21.4%) No impact (10.7%)	High

[139] One of the questions in the survey related to the confidence of respondents in their answers. 25 out of the 28 respondents completed this question. 10 respondents were moderately confident, 9 confident, 2 very confident and 4 not confident. 3 did not answer the question.
[140] I.e., the mini survey might have been completed by many who felt strongly about the topic. Therefore, the results of the survey might largely reflect the opinions of those who opted to fill out the survey on that basis.
[141] Surveys of such sort offer cost saving advantages. See Wright, Kevin B., "Researching Internet-Based Populations: Advantages and Disadvantages of Online Survey Research, Online Questionnaire Authoring Software Packages, and Web Survey Services", *Journal of Computer-Mediated Communication*, Volume 10, Issue 3, 1 April 2005, https://doi.org/10.1111/j.1083-6101.2005.tb00259.x
[142] Foreman, E. K., *Survey sampling principles,* Marcel Dekker Inc, USA, 1991, p. 4.
[143] **High** will result for following combinations: certain and severe; likely and moderate; or likely and severe. **Medium** will result for the following combinations: likely and minor; or unlikely and moderate. **Low** will result for the following combinations: Unlikely and minor; Improbable and no impact.

Impact *(listed in the order administered in mini survey)*	Likelihood (majority view)	Severity (majority view)	Potential significance (low, medium, high)[143]
Change in the freedom of choice and cultures of disabled people	Certain (32.1%) **Likely (57.1%)** Unlikely (7.1%) Improbable (3.6%)	**Severe (42.9%)** Moderate (32.1%) Minor (10.7%) No impact (10.7%)	High
Perpetuation and/or increase economic inequalities	Certain (25%) **Likely (57.1%)** Unlikely (14.3%) Improbable (3.6%)	Severe (33.3%) **Moderate (48.1%)** Minor (14.8%) No impact (3.7%)	High
Affect the freedom of individuals[144]	Certain (14.3%) **Likely (50%)** Unlikely (25%) Improbable (10.7%)	Severe (28.6%) **Moderate (32.1%)** Minor (28.6%) No impact (10.7%)	High
Burden on economic resources due to increasing human lifespans and abilities	Certain (17.9%) **Likely (46.4%)** Unlikely (28.6%) Improbable (7.1%)	Severe (32.1%) **Moderate (35.7%)** Minor (25%) No impact (7.1%)	High
Adverse impact on developing and least-developed nations	Certain (7%) **Likely (50%)** Unlikely (42.3%)	Severe (12%) **Moderate (44%)** Minor (36%) No impact (8%)	High to medium
Social disruption and negative impacts on vulnerable populations (e.g., people with mental and/or physical disabilities, people that face persecution and exclusion)	Certain (7.1%) **Likely (42.9%)** **Unlikely (42.9%)** Improbable (7.1%)	Severe (30.8%) **Moderate (38.5%)** Minor (23.1%) No impact (7.1%)	High to medium
Harm to human health (i.e., harming physical and psychological well-being)	**Likely (67.9%)** Unlikely (25%) Improbable (7.1%)	Severe (32.1%) Moderate (25%) **Minor (39.3%)** No impact (3.6%)	Medium
Increase unemployment by replacing non-enhanced with enhanced workers and the severity of such an impact	Certain (14.3%) **Likely (42.9%)** **Unlikely (42.9%)**	Severe (25.9%) Moderate (29.6%) **Minor (44.4%)**	Medium to low
Adverse impact on the environment (e.g., creation of technological waste, toxicity)	Certain (7.1%) Likely (32.1%) **Unlikely (50%)** Improbable (10.7%)	Severe (7.7%) Moderate (23.1%) **Minor (61.5%)** No impact (7.7%)	Low
Adverse effect on international trade relations	Likely (40.7%) **Unlikely (44.4%)** Improbable (14.8%)	Severe (3.8%) Moderate (30.8%) **Minor (57.7%)** No impact (7.7%)	Low

Table 11: Collated mini survey responses on the likelihood, severity and potential significance of impacts

According to our mini survey data, impacts of *high significance* include: increase in reliance on technology; change in the perception of what makes us human; effects on the freedom of individuals; change in the freedom of choice and cultures of disabled people; creation and/or increase in social inequalities; burden on economic resources due to increasing human lifespans and abilities; and

[144] This question was framed in a general way to assess whether respondents believe there will be an effect on freedom without further specifying whether the effect is positive or negative (i.e., HETs benefitting or adversely affecting freedom). The responses indicate that freedom will be affected.

perpetuation and/or increase in economic inequalities. Impacts with *high to medium* significance include social disruption and negative impacts on vulnerable populations and adverse impact on developing and least-developed nations. Harm to human health can be viewed as a *medium* significance impact. Impacts of *low* significance include adverse impacts on international trade relations and adverse impact on the environment (e.g., creation of technological waste, toxicity).

The results thus show us to varying degrees how the respondents viewed the likelihood and severity of the identified impacts. Some of these (e.g., HETs increasing reliance on technology, social inequalities and causing social disruption) are in line with our research so far. Also, notable are the environmental effects (which are not so well-examined in existing literature).

The responses (while not representative) indicate to us that we need future research on similar questions at a wider and yet more specific level i.e., in terms of specific HET applications. However, the results, especially the questions considered are helpful and could inform the forthcoming work in SIENNA e.g., citizen panels, surveys and determination of questions for legal analysis.

Timelines of impacts
The timing of the impacts will follow and depend on timelines for HET adoption and implementation. These will vary across regions and countries. We list some examples below based on our assessment of the literature on the state of the art.

5-10 years

- Improvements, advancements in health and bodily integrity (e.g., microchip implants in body, wi-fi enabled body parts).
- Creation of economic opportunities, increase in competition and lowering of the costs of HETs.
- Changes in how people work (as the use of HETs gets widespread and abilities to perform tasks is boosted).
- Minor increase in political and social tensions (depending on how HETs are adopted).

10-20 years

- Changes in the lives of families and in education systems (microchip implants in body, wi-fi enabled body parts, e.g., hearts).
- Transformations in the way we live, work and interact (progress in computer-brain interfaces).
- Major increase in political and social tensions (depending on how HETs are adopted and whether measures to mitigate any negative effects are introduced).

4.5 Social & economic impacts on affected parties & other risks

Affected parties
As determined, HETs will have a range of impacts at different levels. The diagram below illustrates the range of affected parties – human and non-human.

Figure 9: Parties affected by HETs

HETs are expected to play an important role in the evolution of the **workforce** in the near future. Although several influences, including the additional technological fields explored in SIENNA (robotics & AI and genomics) among others, will help shape new standards and practices, we have observed many social and economic impacts specific to HET. In some respects, HET is poised to improve working conditions by expanding workers' control over their body and how it functions.[145] However, HET may also bring about negative impacts such as increasing pressure to use HET to remain competitive, perhaps resulting in compulsory enhancement for some workers, and increased capabilities from HET could result in employers justifying work conditions that are already considered intolerable, such as the expectation of dedicating an unhealthy number of hours to one's job every week, due to employees' improved resilience.[146] Specific enhancements could affect individual industries. For example, cognitive enhancements may benefit shift-workers who sometimes suffer mental or physical

[145] MYOB, "The Future of Business, The Augmented Human", May 2016. https://www.myob.com/content/dam/myob-website/docs/misc/future-of-business/MYOB_Future_of_Business-The-Augmented-Human.pdf

[146] Manning, Julia, "Health, humanity and justice: Emerging technologies and health policy in the 21st Century", October 2010. www.2020health.org/dms/2020health/downloads/reports/2020ETjobLOWWEB.pdf; Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.

problems due to challenging working patterns[147], while vision enhancements that allow individuals to see infrared wavelengths or increase their capacity to see in the dark could improve job performance of night watchers, safety inspectors, gamekeepers or other professionals whose jobs require healthy visual acuity.[148] In the long-term, HETs could alter moral expectations for workers responsible for the safety of others, such as doctors or airline pilots, eventually resulting in a new moral obligation for these workers to use HET.[149] Santoni *et. al.* note there is already precedence for such a moral obligation in the case of requiring motor vehicle drivers to use 'brain-invasive medications' to prevent epileptic or diabetic episodes 'for the benefits of other groups of people'.[150] Advances in HET may also modify existing job requirements for some professions, requiring bioethical boards to take responsibility in making regulations for HET independent from industry and government.[151]

Although HET may result in several negative social impacts, expected economic impacts tend to be more positive. The development of the field could lead to a new economic industry that brings together innovation from fields such as physics, engineering and biology, eventually resulting in expansions of existing industries such as healthcare systems.[152] Enhancements may enable people to work in more extreme conditions, reduce work-related illness, make workers more engaged with their work, facilitate better communication, and generally increase job performance and thus improve productivity.[153] Existing PCEs are already sometimes used as productivity enhancers, and some reports suggest that 'microdosing' of the drug LSD as a productivity enhancer is a growing trend in the tech industry.[154] However, HET will require monitoring on long-term consequences, which could be costly.[155] Malfunctioning technology-based human enhancements could cause danger to users and nearby people, and computer security vulnerabilities may involve additional harms for users of

[147] In fact, a medical procedures guide in the United States already explicitly endorses the use of modafinil among emergency medical service providers; see Office of the Secretary of State, State of Maryland, The Maryland Medical Protocols for Emergency Medical Services Providers, *The Maryland Medical Protocols for Emergency Medical Services Providers*, MIEMSS, 2017, p401.
[148] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.; P. J. Nicholson, Mayho, G., & Sharp, C. *Cognitive enhancing drugs and the workplace*. BMA. London. 2015.
[149] Ibid.
[150] Sio, Filippo Santoni De, Nadira Faulmüller, and Nicole A Vincent, "How Cognitive Enhancement Can Change Our Duties," Frontiers in Systems Neuroscience Vol. 8, 2014, p2.
[151] MYOB, op. cit., 2016.; Zwart, Hub, NERRI (Neuro-Enhancement: Responsible Research and Innovation) FINAL Report WP3, July 23, 2015.
[152] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.; Sauter, Arnold, Katrin Gerlinger (Office of Technology Assessment at the German Bundestag, *The pharmacologically improved human: Performance-enhancing substances as a social challenge*, Final report, Technology Assessment Studies, Series 5, 2013. http://www.tab-beim-bundestag.de/en/publications/books/sage-2011-143.html
[153] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012; Coenen, et. al., op. cit., 2009; Manning, op. cit., 2010.
[154] Financial Times, "How Silicon Valley Rediscovered LSD," *Financial Times*, The Financial Times Ltd, August 10, 2017. https://www.ft.com/content/0a5a4404-7c8e-11e7-ab01-a13271d1ee9c;
Corbyn, Zoë, "Get Ahead in Silicon Valley: Take Nootropic Brain Drugs," *The Observer*, Guardian News and Media, July 11, 2015. https://www.theguardian.com/technology/2015/jul/11/hack-yourself-nootropic-drugs-upgrade-mind.
[155] Sauter & Gerlinger, op. cit., 2013.

implanted computational devices such as BCIs or INIs.[156] The emergence of an illegal trade market may follow development of HET[157], and employers who knowingly permit the illicit production, use or distribution of regulated HETs on their premises could face costly legal consequences.[158] If HET remains prohibitively expensive, the promising possibilities of HET improving workplace diversity could be subverted as it may not be cost-effective to equip the less able with expensive technology.[159]

Consumers may face various impacts from HET, e.g., less-informed individuals may face disadvantages compared to individuals able to follow developments in the field, an erosion of the value of the human body resulting in its reduction to a commodity or fashion accessory, and alterations of the rules of social engagement by those who control the development of HET.[160] The nature of regulatory regimes being applied in different ways, such as how digital services and devices tend to attract less oversight than pharmacological interventions, could result in disparities in social attitudes between different categories of HET.[161] Developments in the field could also result in unfairness for individuals who cannot or wish not to risk the side effects of some enhancements, and it's likely to be difficult, if not impossible, to distinguish between consumers who desire HET for leisure from those who wish to wield power over others.[162] There is also a risk of 'over-enhancement', e.g., the use of memory enhancers could result in people losing their natural ability to suppress unwanted memories.[163] Stupple-Harris finds that many existing preconceptions of HET promoted in science-fiction involve a capitalist notion of HET whereby able-bodied people only accidentally become enhanced, and when enhancement is purposefully undertaken it is accessible only to the wealthy elite, demonstrating underlying concerns about the future accessibility of HET in capitalist societies which may influence social narratives around the technology.[164] Existing public attitudes, at least from limited data derived from studies conducted in Western societies, suggest that a majority of individuals find the use of PCEs to improve cognition in healthy individuals to be immoral, although the context, e.g. whether other competitors are also using PCEs, appears to change attitudes slightly.[165]

Economic impacts for consumers include increased demands for consumer goods, job loss and treatment costs due to addiction to HET and the possibility of illegal trade in black markets harming consumers and industry by circumventing the precautions inherent in regulation.[166] Additionally, a focus on transhumanist HET goals could distract from efforts to solve global poverty and inequality issues, as transhumanists rarely 'ponder the issue of suffering', especially 'with regard to the problems

[156] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[157] Sauter & Gerlinger, op. cit., 2013.
[158] Nicholson, et. al., op. cit., 2015.
[159] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[160] Ibid; Coenen, et. al., op. cit., 2009.
[161] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[162] Manning, op. cit., 2010.
[163] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[164] Stupple-Harris, Louis, *Public attitudes to human enhancement*, Sciencewise report, Version 1.0, 2 April 2015.
[165] Ibid.
[166] Manning, op. cit., 2010; Sauter & Gerlinger, op. cit., 2013.

of those who do not live in poverty'.[167] Wealthy consumers are likely to benefit from further advantages as they will be the first who can purchase a greater number and sophistication of new HETs.[168]

Individuals with disabilities are expected to benefit from the development of HETs, and some even see members from this population as natural trail blazers for new HETs, but they may also face additional social and economic impacts. Computational HETs may be vulnerable to unauthorised control or access by hackers, information from HET devices may reduce privacy, independence or freedom, and the existence of HET could reduce the tolerance of difference and limitations in ourselves and others.[169] Malfunctions or unexpected long-term side effects could increase health risks, whether due to surgery during the implementation of HET or from electronic failure affecting the brain, damaging cognitive function in some individuals.[170] Individuals with disabilities may be vulnerable for exploitation of experimental HET as some may hold the perception they have nothing to lose, possibly for altruistic reasons.[171] Many individuals who today are regarded as able-bodied may in the future lose this status for choosing or being unable to follow new standards instilled by HET.[172] Innovations on neuro-prosthetic limbs could lead to what Coenen *et. al.* call 'a cyborgisation of human corporeality'.[173]

More widely, the very concept of enhancement destabilizes the view that there is a species-wide norm, instead suggesting there are only norms for individual people.[174] The development of HET is likely to lead to many HET's becoming accepted as 'normal,' such as how today we see devices such as pacemakers not as implants but integrated parts of a techno-biological body.[175] Advances are expected to require new legal definitions for the concepts of illness, impairment, therapy and medical necessity.[176] Whilst advances in pre-implantation genetic diagnosis is often expected to lead to homogenization such that most parents will feel compelled to choose positive traits for their children, the technology could also enable choices in the opposite direction, e.g., parents with disabilities could use the technology to have a child with their disability to preserve their culture.[177] If HET becomes widely available, the rights for individuals with disabilities to expect their workplace to be designed for their access may be undermined.[178] Eventually, HET may result in a change to what it means to be

[167] Coenen, et. al., op. cit., 2009, p46
[168] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[169] Coenen, et. al., op. cit., 2009; Manning, op. cit., 2010; MYOB, op. cit., 2016; Sauter & Gerlinger, op. cit., 2013; Zwart, op. cit., 2015.
[170] Manning, op. cit., 2010.
[171] Coenen, et. al., op. cit., 2009.
[172] Ibid.
[173] Ibid., p34.
[174] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[175] Manning, op. cit., 2010.
[176] Sauter & Gerlinger, op. cit., 2013.
[177] Coenen, et. al., op. cit., 2009.
[178] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.

human, causing the line between the technological and the natural to fade as individuals become eligible for repairs in similar ways to modern mechanical objects.[179]

Economic impacts for individuals with disabilities include the perpetuation of economic inequalities, e.g. between consumers who can or cannot afford HET, a decrease in funding for restorative treatments in favour of enhancement interventions, and changes to employment rates among individuals with disabilities that limit their daily activities by restoring or equipping them with the necessary skills and tools to maintain a position amongst the workforce.[180] PCEs may enable wider career opportunities for individuals with cognitive disabilities, resulting in increased workplace diversity.[181] Advances in tissue engineering & 3D bioprinting may allow patients with disabilities impacted by diseased or weak vital organs to continue working in labor-intensive professions.[182] Although HETs are likely to become cheaper as the field develops, resulting in HETs supplanting long-term treatment options, it's unclear whether individuals with disabilities who are poor and/or live in low-income countries will gain access to new HETs.[183] The price of HET devices and interventions may also create complex issues regarding ownership of these technologies.[184]

Elderly individuals are likely to face several of the same impacts as individuals with disabilities, such as the need for new definitions of concepts including illness and medical necessity, the normalisation and social expectation to use certain HET and uncertainties about the ownership of some HET interventions or devices. In addition, cosmetic enhancements may benefit the elderly by enabling them to remain competitive in professions where the appearance of being younger has implications for employment, and in the long term an ageing workforce may erode expectations of youthful appearances in such professions.[185] The elderly may be especially susceptible to risks of addiction to HETs, as they may see HET as a necessary tool to remain relevant in an increasingly technological world.[186] Economic impacts include a huge market potential for the appraisal of funding and support for R&D into neurological conditions prevalent with an ageing population.[187] If addiction to HET becomes problematic, there may be financial costs involved as well, such as enrolment in rehabilitation programs.[188] Advances in tissue engineering may enable bone replacement interventions that could involve strengthening bone structures beyond standard expectations, allowing the elderly to avoid leaving jobs due to complications from weak or broken bones.[189] Hearing aids already enable some elderly persons to

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[179] Manning, op. cit., 2010; MYOB, op. cit., 2016; Zwart, op. cit., 2015.
[180] Manning, op. cit., 2010; Sauter & Gerlinger, op. cit., 2013; Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[181] Ibid.
[182] Ibid.
[183] Coenen, et. al., op. cit., 2009.
[184] Coenen, et. al., op. cit., 2009; Manning, op. cit., 2010; Zwart, op. cit., 2015.
[185] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[186] Manning, op. cit., 2010.
[187] Ibid; Sauter & Gerlinger, op. cit., 2013.
[188] Sauter & Gerlinger, op. cit., 2013
[189] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.

function successfully in the workplace; further development could also improve hearing ability in noisy or reverberant situations.[190]

Children may also face similar social and economic impacts associated with the elderly or individuals with disabilities. Changing health norms may impact whether children who would uncontroversially be classified as able-bodied today could lose this status without HET in the future. Children may experience a permanent pressure to live up to increasing social demands and face increased competition and inequality as the ubiquity of some HETs becomes established.[191] Although the risk of computational HET devices for hacking exists for many parties, this is especially true for children who may be careless or unfamiliar with such devices.[192] Children, especially the youngest, are easily harmed when unsupervised, and the potential invasiveness of some HET applications make this an especially pertinent issue.[193] Currently, the long term effects of many HETs, in particular PCEs, is unknown, which may be especially applicable to children whose brains are still developing, making long term studies necessary even though the potential risk makes it difficult for these studies to gain approval.[194] We would like to note that we were unable to find further economic impacts specific to children, possibly suggesting that this group remains understudied in terms of economic concerns.

Patients, again, are expected to share several of the same social and economic impacts as individuals with disabilities, elderly and young individuals, as patients may include members from any of these groups. However, patients taken as a separate party illuminates a few impacts exclusive to, for example, populations involved in clinical trials. Informed consent issues will apply to several medical and non-medical HET, such as cosmetic surgery, PCE and neurostimulation.[195] Clinical trials on patient groups are likely to expose side-effects of new HETs, making this group especially vulnerable to unanticipated harms from the technology.[196] Coenen *et. al.* note that the technological imperative is likely to involve a transition of interventions currently deemed to be restorative treatments into enhancements because engineers will be driven to continue improving HET, potentially resulting in altered baseline norms once a level of HET becomes commonplace.[197] Although patients are likely to face similar economic impacts as other previously mentioned groups, we found it difficult to note unique economic impacts for this party, with the exception that HET has been found to be one of the drivers of the tendency toward medicalization, which may increase funding in health research if the trend continues.[198]

Soldiers are an important party of HET users, as military research agencies are currently among the most prolific forces in funding R&D for non-therapeutic HET.[199] Soldiers are more likely to adopt HET,

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[190] Ibid.
[191] Sauter & Gerlinger, op. cit., 2013; Zwart, op. cit., 2015.
[192] Zwart, op. cit., 2015.
[193] Ibid.
[194] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[195] Coenen, et. al., op. cit., 2009.
[196] Manning, op. cit., 2010.
[197] Coenen, et. al., op. cit., 2009, p20.
[198] Ibid.
[199] Ibid.

especially in the experimental stage, as increased capabilities are likely to be seen as a survival-increasing edge worth the long term risks of side effects, and military units may choose to collectively adopt HET out of solidarity to decrease risk to group members.[200] However, soldiers may pose a threat upon leaving the army after they have been 'weaponized', which may create special difficulties in determining the ownership of certain enhancements. In addition, military interests could prompt an enhancement 'arms race'[201] to ensure soldiers are equipped with the most advanced HET in a war scenario.[202]

Arguably, **sportspersons** have been among the most-affected parties of HET to date. Although we were unable to find many impacts exclusive to sportspeople, many of the above impacts will also apply to this group, such as issues about the ownership of HET devices, risks of hacking, risk of addiction and increased competition. Competition is key for this party, as the motivation to enhance physical performance remains pronounced for sportspeople, as can be seen in 'doping' scandals over the previous few decades.[203] Genetic enhancements may provide special benefits to professional athletes, as the technology could potentially develop to allow what are currently considered career-ending injuries to heal.[204] If such techniques are permitted, existing views on HET and fairness in sports will need to change.

HETs will also have impacts on the **planet** and **animals** – both of which we also see as affected parties. Biomedical human modifications could help the human race adapt to climate change.[205] This might increase pressure on the planet as humans capabilities advance[206] or population levels rise, supported by HETs. HETs (like other similar technologies) and their widespread adoption might also create pressure on the environment by generating further technological waste. Animals might also experience increased impacts of HETs, e.g., increase competition between humans and animals for natural resources, and impact on animal welfare vis a vis an increase in testing of HETs.

HETs will not impact every party equally. Enhanced individuals and societies might reap the benefits at the cost of unenhanced individuals and societies. Some groups might be particularly vulnerable[207], e.g., children – especially if they have no 'effective' choice or control in deciding to use a HET.

The impact on any party will vary depending on the following factors:

- Access to HETs (and whether such access is affordable)

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200 Zwart, op. cit., 2015.
201 Sparrow, R. "Enhancement and obsolescence: Avoiding an 'enhanced rat race'", *Kennedy Inst Ethics J.*, 2015 Sep, Vol. 25, Iss. 3, pp. 231-60.
202 Zwart, op. cit., 2015; Coenen, et. al., op. cit., 2009.
203 Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
204 Coenen, et. al., op. cit., 2009.
205 Andersen, Ross, "Biomedical human modifications could help the human race adapt to climate change", *The Atlantic,* 12 March 2012. https://www.theatlantic.com/technology/archive/2012/03/how-engineering-the-human-body-could-combat-climate-change/253981/
206 Miah, Andy, "The ethics of human enhancement", *MIT Technology Review*, 8 Sept 2016. https://www.technologyreview.com/s/602342/the-ethics-of-human-enhancement/
207 ter Meulen, R., "The Moral Ambiguity of Human Enhancement", in S. Bateman J. Gayon, S. Allouche, J. Goffette, M. Marzano (eds), *Inquiring into Human Enhancement. Health, Technology and Society*, Palgrave Macmillan, London, 2015, pp. 86-99 [p. 86].

- Concentration of HETs (with the wealthy, or in wealthy or technologically advanced countries)
- Openness to HETs (based on cultural, religious, personal or other determinant factors)
- Use of HETs (whether supported or proscribed by regulation, policy-making and standards)
- Capacity to cope and readiness to address any negative effects and maximise benefits of HETs to promote human well-being and good.

Geographical reach of the impacts

The impacts of HETs will be greater (this includes positive and negative impacts) and more widespread in industrialised countries and where HETs research is already making great strides (e.g., USA, South Korea where leading companies developing such technologies are based[208]) and where people are open to the use of HETs (i.e., the NERRI project survey suggests that the public in Spain, Portugal, the UK, and USA are more open to enhancement as compared to those in Austria, Denmark, and Germany[209]). Then again, the cultural and political conduciveness towards human enhancement that leads to a wider (and even unregulated) growth in HETs might see both positive and negative impacts occur in countries outside the affluent West.

Supporting or undermining affected communities' or societal values

The transformation of individuals (healthy or otherwise) made possible by HETs would lead to a change in the manner individuals perceive themselves[210] (for instance as 'better humans') and their role in society, their workplace etc. A report highlights how opponents of human enhancement suggest profound changes will occur very fast and 'humans will suffer a major identity crisis, which will have significant implications for society'.[211] The same report highlights opposing views that suggest this might not be the case at all i.e., 'technological changes will happen so gradually that humans will be capable of adapting naturally to their new environments or circumstances just as they did during the industrial age or the more recent electronic age or indeed throughout the entire history of human evolution.'[212]

On the one hand, HETs may help individuals achieve their life and societal goals and on the other hand, the positive effect of such achievement itself might be undermined by the fact that this has been achieved via technological shortcuts – i.e., in this case, HETs.[213] Brey too highlights the issue of 'devaluation of achievement through the disposability of effort' and further commodification of the human body.[214]

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[208] Mordor Intelligence, Human Enhancement Market - By Product (In Built Enhancement, Wearable Enhancement), Application (Healthcare, Defense), Geography, Trends, Forecast - (2017 - 2022), October 2017. https://www.mordorintelligence.com/industry-reports/global-human-enhancement-market-industry

[209] CORDIS, Final Report Summary - NERRI (Neuro-Enhancement: Responsible Research and Innovation), 2016. https://cordis.europa.eu/result/rcn/192408_en.htm

[210] Brey states, "Human enhancement does not only affect ontogenetic identity, it also affects bodily identity (how we perceive our bodies) and social identity (how we perceive ourselves in relation to others)". See Brey, P., "Human Enhancement and Personal Identity", in J.K.B Olsen, E. Selinger, S. Riis, (eds.), *New Waves in Philosophy of Technology. New Waves in Philosophy Series*, Palgrave Macmillan, New York, 2009, pp. 169-185.

[211] The Irish Council for Bioethics, Human Enhancement: Making People Better or Making Better People?, Undated. http://www.rte.ie/science/human_enhancement.pdf

[212] Ibid.

[213] Miah, Andy, "The ethics of human enhancement", *MIT Technology Review*, 8 Sept 2016. https://www.technologyreview.com/s/602342/the-ethics-of-human-enhancement/

[214] Brey, op. cit., 2009.

Based on our research, we find that the societal values that are and will be most under threat from HETs include:

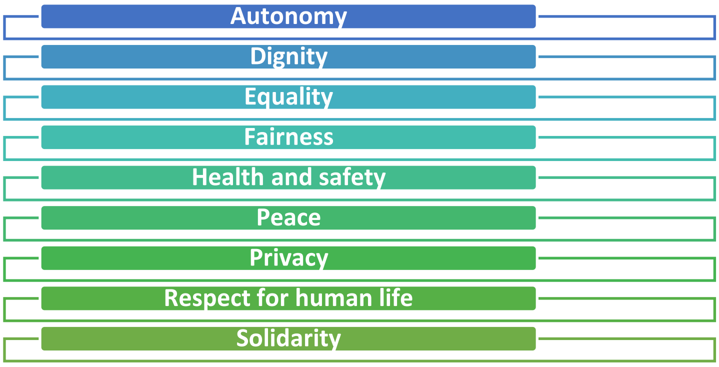

Figure 10: Values most affected/likely to be affected by HETs

Resilience and vulnerability of the potentially affected communities

The EC Communication on the EU Approach to Resilience, defines resilience as 'the ability of an individual, a household, a community, a country or a region to withstand, to adapt, and to quickly recover from stresses and shocks'.[215] Resilience, here, has two critical aspects: the inherent strength of a party and its capacity to bounce back.

Affected community	Resilience factors
Animals	The resilience of animals to the negative impacts of HETs will depend on whether factors exist to help them cope with the effects of HETs, their ability to adapt to post-HET state or return to pre-HET state, and the improvement measures implemented to minimise pain and suffering and/or improve animal welfare.
Consumers	The resilience of consumers to bounce back from the negative impacts of HETs will depend on their access to more accurate information which will help them to make better choices (e.g., accurate advertising of HETs, debunking of excessive claims) safety regulation and good enforcement of consumer rights.
Disabled	For the disabled, as Craig explains resilience includes 'protective factors included attributes that minimize risk or act as a buffer by cushioning the person against negative outcomes, and included environmental, interpersonal, and individual personal factors. Being resilient, therefore, described a process that involved someone who had assets and resources that enabled him or her to self-protect and thus overcome the adverse effects of risk exposure.'[216] Individuals need to have: resilient attitudes, beliefs and personality, adequate health support, emotional, physical, and material support from their families, social support from friends, others and community members; their basic subsistence needs met; and an inclusive-minded society.[217]

[215] European Commission, Communication from the Commission to the European Parliament and the Council – The EU Approach to Resilience: Learning from Food Security Crises, COM(2012) 586 Final, Brussels, 3.10.2012. http://ec.europa.eu/echo/files/policies/resilience/com_2012_586_resilience_en.pdf

[216] Craig, Ashley, "Resilience in People with Physical Disabilities", *The Oxford handbook of rehabilitation psychology*, 2012, p. 474

[217] Richie, Beth, Angela Ferguson, Maria Gomez, Dalia Khoury, and Zahabia Adamaly, "Resilience in survivors of traumatic limb loss", *Disability Studies Quarterly* 23, No. 2, 2003. http://dsq-sds.org/article/view/412

Affected community	Resilience factors
Patients	From the patient perspective, one study[218] highlights how mechanisms that include genetic, epigenetic, developmental, psychological, and neurochemical factors underlie the development and enhancement of resilience and factors that predict vulnerability to stress and susceptibility in the face of stress and trauma. This would be equally applicable to the impacts of HETs which although overall might bring benefits to patients, might also lead to some cases of stress (unequal access, loss of access to HETs) and trauma (e.g., in the case of addiction to HETs).
Planet	Rockstrom et al identified planetary boundaries that must not be transgressed to prevent human activities from causing unacceptable environmental change[219]. HETs must be prevented from causing pressure or further transgression of the planetary boundaries.
Sportspersons	Five main families of psychological factors protect sportspersons from negative effects of stresses – i.e., personality, motivation, confidence, focus, perceived social support.[220] Ensuring these are present and supported in sportspersons using HETs, would help boost resilience.
Soldiers	The impact of HET soldiers will depend on their design and use.[221] The resilience of soldiers to bounce back from the negative effects of the use of such technologies especially the adverse effects on their human rights will depend on measures put in place to protect soldiers i.e., ethical, safety, policy and regulatory measures.
Elderly people	With respect to the elderly, resilience is associated with the availability of better health and well-being, higher levels of social and communal interaction, increased levels of spirituality or interventions to promote resilience.[222] This vulnerable group should be adequately supported and active measures taken to boost their resilience to any negative impacts HETs might bring for them.
Children	Resilience in children depends on a variety of factors[223] related to the individual (e.g., independence, autonomy, willingness and capacity to learn, problem-solving skills, communication skills), family (e.g., nurturance, trust, encouragement, close bonds, sufficient financial and material resources) and the wider community (e.g., neighbour and non-kin support, peer contact, good experiences, positive adult role models). Resilience in relation to HETs would depend on the avoidance of risk (where possible), effective use of strategies (regulatory and societal) at various levels to counteract the adverse impacts of HETs.

[218] Wu, G., A. Feder, H. Cohen, J. J. Kim, S. Calderon, D.S. Charney and A. A. Mathé, "Understanding resilience", *Frontiers in Behavioral Neuroscience*, *7*, 10, 2013. http://doi.org/10.3389/fnbeh.2013.00010

[219] Rockström, Johan, Will Steffen, Kevin Noone, Åsa Persson, F. Stuart Chapin III, Eric F. Lambin, Timothy M. Lenton et al., "A safe operating space for humanity", *Nature* 461, No. 7263, 2009. https://www.nature.com/articles/461472a

[220] Sarkar, M. and D. Fletcher, "Psychological resilience in sport performers: a review of stressors and protective factors", *Journal of Sports Sciences*, 32 (15), 2014, pp.1419-1434.

[221] Dinniss, Heather A. Harrison and Jann K. Kleffner, "Soldier 2.0: Military Human Enhancement and International Law", *Dehumanization of Warfare*. Springer, Cham, 2018, pp.163-205, [p. 205].

[222] Centre for Policy on Ageing, "Resilience in older age", May 2014. http://www.cpa.org.uk/information/reviews/CPA-Rapid-Review-Resilience-and-recovery.pdf

[223] NCH - The Bridge Child Care Development Service, "Literature Review: Resilience in Children and Young People", June 2007. https://www.actionforchildren.org.uk/media/3420/resilience_in_children_in_young_people.pdf

Affected community	Resilience factors
Workforce and management	Resilience in the workforce to disruptions, shocks or stresses caused by HETs would depend on whether its sensitivities to these had been reduced and whether the workforce had the necessary skills, knowledge and experience to overcome the difficulties HETs might raise. Resilience in the management would depend on the whether and how management was able to anticipate, prepare for, respond and adapt to change and disruptions to enable the organisation to survive the impacts of HETs and prosper.[224]

Table 12: Affected communities & resilience factors

While as demonstrated above resilience will be conditional on the presence of certain factors, given our research so far and the state of the art in HETs, the **most vulnerable communities** will be patients, disabled, elderly and children (e.g., due to lack of choice and decision-making power in use of HET coupled with lack of understanding of full implications). The impacts of HETs on such groups should be carefully monitored (and if necessary regulated).

Potential for unmanageable change

Unmanageable change refers to change that is extremely difficult to control or influence, and that is not easy to deal with.

Some of the previous work on human enhancement provides some clues about whether impacts of HETs will cause unmanageable change in communities. For instance, the 2009 EU Parliament STOA report states, 'the technologies and trends involved can have both beneficial and adverse effects on several kinds of political domain, provide opportunities for individuals and for society, present new risks, create new needs and social demands, and challenge crucial cultural notions, social concepts and views of the human condition.'[225] It also stated that 'human enhancement can have far-reaching implications both for individuals and for society and, therefore, also for the EU.'[226] As the state of the art and SEIA results reveal, such implication are already evident. The potential for causing unmanageable change will depend on how innovations in HETs proceed, their adoption, use and applicability.

One of the impacts identified in this exercise that we see pointing to unmanageable change relate to the changing nature of the 'human' or what we have previously come to know and acknowledge as 'human'. Other impacts are of a more generic nature, widely applicable not just to HETs and for which societies have coping and change management mechanisms.

Costs of the impacts

HETs have the 'potential to provide many benefits to both individuals and society provided that it is fairly distributed',[227] but we also need to consider the costs of their impacts. Some of these costs could

[224] Adapted from the BSI definition of Organizational Resilience. See BSI, Organizational Resilience. Harnessing experience, embracing opportunity, Executive summary, Nov 2015. https://www.bsigroup.com/Global/revisions/Org-Resilience-Exec-summary2--FINAL-25Nov15.pdf
[225] Coenen, et. al., op. cit., 2009.
[226] Coenan, op. cit., 2009, p. 147.
[227] Swindells, Fox, "Economic Inequality and Human Enhancement Technology", *Humana Mente Journal of Philosophical Studies*, 2014, Vol. 26, 213-222. http://www.humanamente.eu/PDF/Issue26_Paper_Swindells.pdf

be direct (attributable to the technology itself) or indirect (not attributable to the technology but connected to the broader impact is has on society). Some costs may be avoidable by virtue of being fixed in the long run or unavoidable due to their variability in the short run. One news item suggests that HET,

> will undoubtedly come at a price and someone will have to foot the bill. If only those who can afford it opt for human enhancement, the appalling wage gap in our society will become ever greater and social mobility will decrease. If the wealthy can increase their intelligence and become more physically able, they will likely increase their earning power. In this case, the rich can only become richer.[228]

While it is not feasible within the limited timeframe to do a detailed assessment of the costs of the impacts, our analysis highlights the following costs (non-exhaustive) of these impacts:

- Cost burdens due to additional pressure on existing resources (vis a vis overpopulation[229], greater production needs, payment for the technologies, increased life expectancy and associated costs) especially in the healthcare sector.
- Cost of social inequality[230] that HETs will perpetuate or promote.
- Costs associated with oversaturation of the market (increasing operating costs and new competition).
- Costs of providing benefits/taking care of those disadvantaged or marginalised in any way by the implementation of HETs (loss of earnings costs).
- Costs of dealing with environmental waste created by HETs.
- Cost of enforcing prohibitions/restrictions/regulations on the use of HETs.

Mitigation of negative impacts

Our literature review and mini survey results (recommendations of the stakeholders who responded to the survey) indicated that there are many measures that could help and be used to mitigate the negative impacts of HETs. We classify these measures into four types: policy and regulatory measures, technological or industry measures, society-level measures and individual-level measures.

Policy and regulatory measures (responsibility: policy-makers, regulators, national ethics committees)

- Keep impact high on the agenda in both medical research and healthcare policy[231]
- Create social policies, broaden social reform and inclusion, democratic regulation of industries and technologies (c.f. Uber)[232]
- Get input from unions and workers' representatives[233]
- Investigate whether the available statutory regulations and their procedural and institutional implementation appear appropriate[234]

[228] Laboratory News, Human enhancement: will the benefits outweigh the costs?, Editorial comment, *Laboratory News*, 13 Dec 2012. https://www.labnews.co.uk/comment/editorial-comments/human-enhancement-will-the-benefits-outweigh-the-costs-13-12-2012/
[229] The Irish Council for Bioethics, Human Enhancement: Making People Better or Making Better People?, Undated. http://www.rte.ie/science/human_enhancement.pdf
[230] Noting that, inequality adversely impacts human health, well-being, security and comes with financial costs.
[231] Brey, op. cit., 2009.
[232] SIENNA mini survey Feb 2018.
[233] SIENNA mini survey Feb 2018.
[234] Sauter & Gerlinger, op. cit., 2013.

- Carefully regulate based on technology assessment outcomes[235], when working with HETs related to disability[236], to safeguard the rights of vulnerable populations[237]
- Heavily regulate major advances in attempt to distribute incremental advances to the public at large[238]
- Create regulatory and ethical bodies[239]
- Monitor consequences[240]
- Create EU platform for monitoring and discussing human enhancement issues[241]
- Restrict funding of technologies with potential to disrupt the social fabric and values of the EU
- Develop a framework to evaluate new technologies – to ensure these are ethically acceptable to society, and that 'human enhancing' technologies improve not only the individual, but also the broader community well-being[242]
- Look in broader context; not just at HETs per se[243]
- Promote equal accessibility and informed decision making (for all)[244]
- Promote ethical and social measures[245]
- Engage with significant moral, ethical and safety concerns to ensure responsible research and development in this field[246]
- Have continuous ethical discussion to inform the elaboration of new public policies to minimise adverse effects of HETs[247]

Technological/industry measures (responsibility: companies, industry associations, HET designers and innovators)

- Design innovative governance models that ensure that their benefits are maximized and the associated risks kept under control[248]
- Ensure responsible design of human enhancement technologies[249]
- Reflect more on what kind of technology we have in mind, whether and when it will be available, and for what goal[250]
- Continual assessment of HETs,[251] e.g., identify ethical, legal, societal, economic impacts)
- Increase the level of security[252]

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[235] Brey, op. cit., 2009.
[236] Bose, Dev, "Defining and Analyzing Disability in Human Enhancement", in *Global Issues and Ethical Considerations in Human Enhancement Technologies*, 2014, pp. 191-202.
[237] SIENNA mini survey Feb 2018.
[238] SIENNA mini survey Feb 2018.
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[241] Coenen, et. al., op. cit., 2009.
[242] Fernandez, Alvaro, "Five reasons the future of brain enhancement is digital, pervasive and (hopefully) bright", 01 May 2017. https://www.weforum.org/agenda/2017/05/five-reasons-the-future-of-brain-enhancement-is-digital-pervasive-and-hopefully-bright
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[249] SIENNA mini survey Feb 2018.
[250] SIENNA mini survey Feb 2018.
[251] SIENNA mini survey Feb 2018.
[252] MYOB, op. cit., 2016.

- Strengthen ethical management[253]
- Provide information and education on the benefits of human enhancements, how their use will be monitored, as well as the safety and effectiveness of these technologies[254]

Society-level measures (responsibility: academia, civil society, media)

- Make a nuanced analysis of the issues alongside critical reflections by all stakeholders supported, wherever possible by clear arguments in the public domain[255]
- Engage publics in open dialogue[256]
- Scientists need to work together with social scientists, philosophers, ethicists, policy-makers and the public to discuss the ethical and moral consequences of enhancement (AMS et al, HE and the future of work, 2012)
- Engage in bio-political debate and social control of future developments[257]
- Consider at all times the best interests and future welfare of the resulting children[258]
- Technology assessment and scenario building for new HETs[259]
- Identify, anticipate in an informed way and analyse their normative and sociocultural impact at their liminal stage[260]
- Look in broader context; not just at HETs per se[261]

Individual-level measures (responsibility: individuals using HETs, considering their use, affected by such HETs)

- Exercise caution[262] and carefully evaluate what enhancements are on offer, their advantages and disadvantages - question the desirability and necessity of enhancement[263]
- Object to the use of HETs that pose high-risk to one's rights and freedoms
- Elect politicians who care about inequality and climate change[264]

As shown above, many of the mitigation measures seem to be directed at the policy or regulation level. None of these are novel per se, and are constantly used in different technological domains to varying effects and degrees to mitigate adverse consequences, and with different levels of success.

[253] MYOB, op. cit., 2016.
[254] AARP Research, "U.S. Public Opinion & Interest on Human Enhancements Technology", Jan 2018. https://doi.org/10.26419/res.00192.001
[255] UK House of Commons Science and Technology Committee, "Human Enhancement Technologies in Sport", Second Report of Session 2006–07 Report, together with formal minutes, oral and written evidence ordered by The House of Commons, 7 February 2007. https://publications.parliament.uk/pa/cm200607/cmselect/cmsctech/67/67.pdf
[256] Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering and the Royal Society, op. cit., 2012.
[257] Sauter & Gerlinger, op. cit., 2013.
[258] Bostrom, Nick, Rebecca Roache, "Ethical Issues in Human Enhancement", in Jesper Ryberg, Thomas Petersen and Clark Wolf (eds.), *New Waves in Applied Ethics*, Palgrave Macmillan, 2008, pp. 120-152.
[259] Brey, op. cit., 2009.
[260] SIENNA mini survey Feb 2018.
[261] SIENNA mini survey Feb 2018.
[262] Miah, op. cit., 2016.
[263] Manning, op. cit., 2010.
[264] SIENNA mini survey Feb 2018.

4.6 SEIA recommendations

As this SEIA reveals, HETs will have a variety of impacts on a range of different parties; however, based on our analysis there are some impacts that seem to stand out more than others (of course this depends on how HETs are used and whether measures exist to address any negative effects and boost the positive impacts). Below we make some recommendations based on the preceding analysis.

Short-term and medium-term recommendations

- There is a need for greater and refreshed dialogue on impacts (something this SEIA has tried to kick-start), particularly one that looks at specific applications in specific contexts. SIENNA will carry forward this dialogue via its forthcoming activities.
- There is a need to watch the impacts in terms of vulnerable populations, as HET applications advance.
- Industry should assess HETs for ethical and societal impacts at design and development stages.
- There is a need for better information for users of HETs.

Long-term recommendations

- Regulation and policy-support measures to promote socially responsible HETs and ethical practices (without curtailing innovation).

5. Conclusion

Following our research for this state-of-the-art review, we find HET to be an emerging field at the periphery of entering a new stage of scientific research, development and innovation. Although it is difficult today to identify individual researchers actively attempting to develop HET, we expect this will begin to change over the next 10 years. Existing HET applications, such as consumer-market neurostimulation devices, cosmetic enhancements and PCEs, are either at or very near to entering mature stages of development. Social approval of such technologies should pave the way for subsequent advances, soon resulting in a thriving, complex field with the long-term potential to alter the course of human evolution.

Subsequent SIENNA work will explore ethical and legal issues along with societal acceptance and awareness of HET with the goal of delivering a proposed ethical framework for the emerging field. In this report, we have identified six subcategories of enhancement targets (affective, moral, cognitive, physical, cosmetic and longevity) found within five prominent enhancement domains (healthcare, education, workplace, military/defence and recreation or home). Many of the applications identified in this review exist as more of a promise than as currently usable technologies, but we expect several of the anticipated technologies to become available over the next 20 years.

In addition to defining and demarcating the field and identifying existing and expected technologies, our socio-economic impact assessment leads to the following recommendations to address any negative effects and boost the positive impacts of HETs. In the short- to medium-term, there is a need for greater and refreshed dialogue on impacts (something this report's SEIA has tried to kick-start), particularly one that looks at specific applications in specific contexts. SIENNA will carry forward this dialogue via its forthcoming activities. There is also a need to watch the impacts in terms of vulnerable populations, as HET applications advance. Industry should assess HETs for ethical and societal impacts at design and development stages. Finally, there is need for better information for users of HETs. In the long-term, **r**egulation and policy-support measures need to promote socially responsible HETs and ethical practices (without curtailing innovation).

Since 2009, the field of HET has seen significant progress in areas such as 3D-bioprinting and wearables, and has moved closer to bringing INIs into active R&D. However, several applications, in particular PCEs, have seen comparably little development from a previous review of the field.[265] A significant portion of HETs exist more as a promise than a reality, therein several expected technologies require breakthroughs that are impossible to know whether they will be overcome in five, ten, twenty or more years. Although it's unlikely all of the expected technologies discussed above will follow our predicted timeline, we expect at least some significant advances will be made, resulting in social, economic and environmental impacts requiring careful exploration of the issues to navigate to the best outcomes.

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Annexes

Annex 1. Mini-survey form

SIENNA HETs SEIA survey

QUESTIONS   RESPONSES 28

Section 1 of 3

SIENNA - assessing impacts of human enhancement technologies

This is a mini survey to assess and evaluate the significance of some socio-economic impacts of human enhancement technologies (HETs).

The SIENNA project (Stakeholder-informed ethics for new technologies with high socio-economic and human rights impact) receives funding under the European Union's H2020 research and innovation programme under grant agreement No 741716. For more information about the project, please visit www.sienna-project.eu

Trilateral Research Ltd, the project's deputy co-ordinator, is administering this survey on behalf of SIENNA. The answers you provide will inform SIENNA's forthcoming state of the art review of HETs.

SIENNA defines "human enhancement" as a modification aimed at improving human performance and brought about by science-based and/or technology-based interventions in or on the human body. HETs, broadly speaking, include applications and interventions that permanently or temporarily improve or change human capabilities.

SIENNA defines "impact" as a change – positive and/or negative, direct or indirect, in whole or in part – caused by or associated with human enhancement technologies. "Likelihood" refers to the chance that something might happen. "Severity" refers to the gravity or seriousness of the impact.

The purpose of this survey is the determine the significance of the socio-economic impacts of HETs by examining their likelihood of occurring and their severity. It should take around 15 minutes to complete. You do not need to sign in, and the survey does not collect any personal data. Your responses will not be used in any way that would allow your identification. Anonymised research data will be archived in the SIENNA institutional repository to make them available to other researchers in line with current data sharing practices. Your participation is entirely voluntary, and you can withdraw at any time.

If you have any questions, please contact Rowena Rodrigues: rowena.rodrigues[at]trilateralresearch.com

The survey closes on 12 Feb 2018.

1. **Type of stakeholder (industry, academia, civil society, media, policy-maker, regulator, ethics committee, individual, other)** *

2. **Country** *

3. 1a. What is the likelihood of HETs increasing our reliance on technology?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

4. 1b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

5. 2a. What is the likelihood of HETs changing the perception of what makes us human?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

6. 2b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

7. 3a. What is the likelihood of HETs affecting freedom of individuals?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

8. 3b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

9. 4a. What is the likelihood of HETs changing the freedom of choice and cultures of disabled people?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

10. 4b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

11. 5a. What is the likelihood of HETs harming human health (i.e., harming physical and psychological well-being)?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

12. 5b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

13. 6a. What is the likelihood of HETs creating and/or increasing social inequalities?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

14. 6b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

15. 7a. What is the likelihood of HETs causing social disruption and negative impacts on vulnerable populations (e.g., people with mental and/or physical disabilities, people that face persecution and exclusion)?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

16. 7b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

17. 8a. What is the likelihood of HETs causing a burden on economic resources due to increasing human lifespans and abilities?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

18. 8b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

19. 9a. What is the likelihood of HETs increasing unemployment by replacing non-enhanced with enhanced workers?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

20. 9b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

21. 10a. What is the likelihood of HETs perpetuating and/or increasing economic inequalities?
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

22. 10b. What will be the severity of such an impact?
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

23. **11a. What is the likelihood of HETs adversely affecting international trade relations?**
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

24. **11b. What will be the severity of such an impact?**
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

25. **12a. What is the likelihood of HETs having an adverse impact on developing and least-developed nations?**
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

26. **12b. What will be the severity of such an impact?**
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

27. **13a. What is the likelihood of HETs having an adverse impact on the environment (e.g., creation of technological waste, toxicity)?**
Mark only one oval.
- Improbable
- Unlikely
- Likely
- Certain

28. **13b. What will be the severity of such an impact?**
Mark only one oval.
- No impact
- Minor
- Moderate
- Severe

29. **14. How confident are you with your answers?**
Mark only one oval.
- Very confident
- Moderately confident
- Confident
- Not confident

30. **15. Do you think it is possible to mitigate the negative impacts of HETs? If so, how?**

31. **Thank you for completing this survey! Please provide us your feedback and suggestions.**

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Annex 2. Mini survey results on likelihood and severity of impacts

The sections below illustrate the responses to the specific mini survey questions.

1. Likelihood of HETs increasing our reliance on technology and the severity of such an impact

All 28 respondents answered the question on what is the likelihood of HETs increasing our reliance on technology. The majority (20) found it likely that HETs would increase our reliance on technology. A few (5) were certain. Only 2 (7.4%) respondents found it unlikely and 1 (3.7%) improbable.

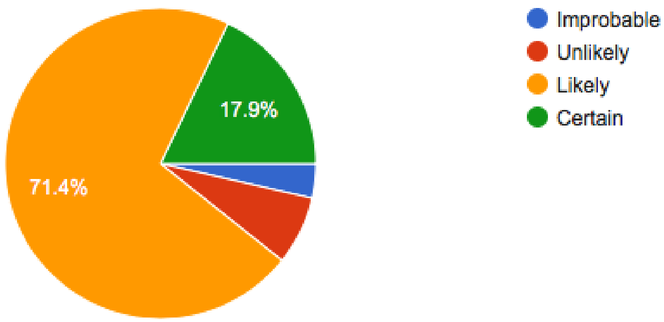

Fig 1a: Likelihood of HETs increasing our reliance on tech

In terms of severity (completed by 26 respondents), nearly half (14) felt this would be moderate. 11 respondents thought such an impact would be severe, while the remaining (2) felt it would be minor.

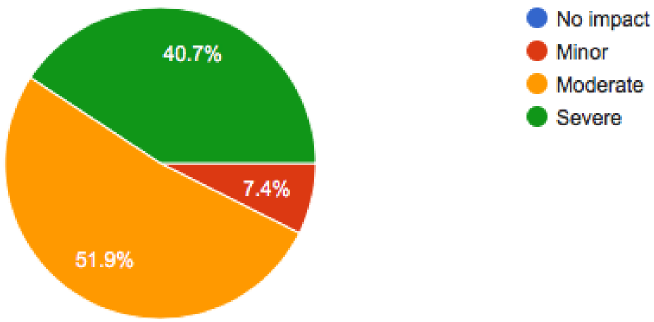

Fig 1b: Severity of the impact

2. Likelihood of HETs changing the perception of what makes us human and the severity of such an impact

Majority of the respondents (19 likely and 1 certain) opined that HETs were likely to change the perception of what makes us human. 2 respondents thought it improbable while 6 thought it unlikely.

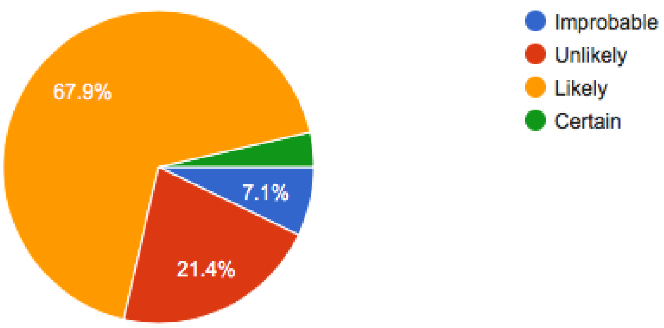

Fig 2a: Likelihood of HETs changing the perception of what makes us human

In terms of severity, the results reveal a moderate to severe outlook for this impact. 11 respondents indicated a moderate impact, 8 severe, 6 minor and only 3 thought there would be no impact.

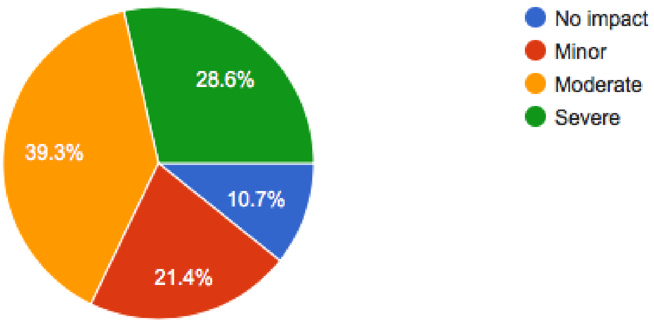

Fig 2b: Severity of the impact

3. Likelihood of HETs affecting freedom of individuals and the severity of such an impact

Nearly half the respondents (14) thought that it likely that HETs would affect the freedom of individuals; in addition, 4 were certain this was likely. 7 thought it unlikely while 4 thought it improbable.

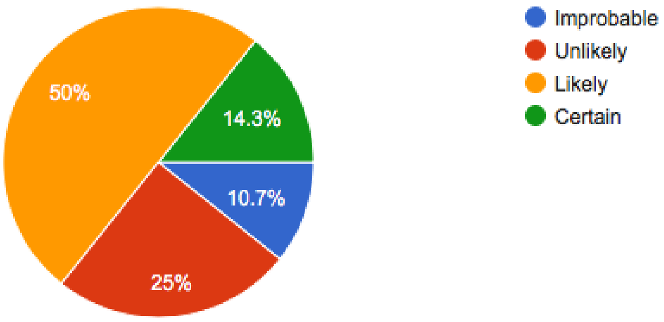

Fig 3a: Likelihood of HETs affecting freedom of individuals

The severity of such impact was viewed as moderate by 9; 8 as severe and 8 as minor. 3 respondents thought there would be no impact.

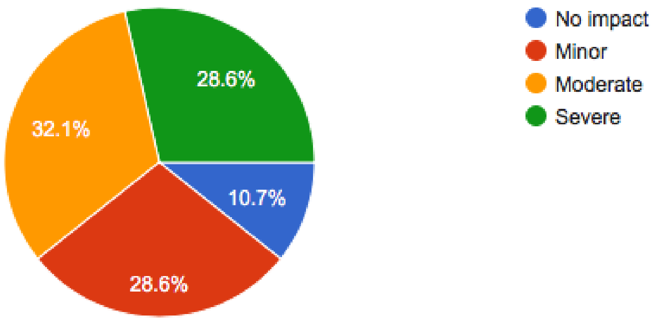

Fig 3b: Severity of the impact

4. Likelihood of HETs changing the freedom of choice and cultures of disabled people and the severity of such an impact

Just over half the respondents (16) thought that HETs would likely change the freedom of choice and cultures of disabled people. 9 respondents were certain. 2 thought it unlikely and only 1 thought it improbable.

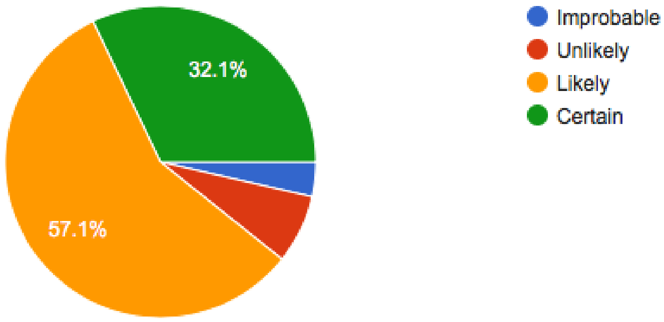

Fig 4a: Likelihood of HETs changing the freedom of choice and cultures of disabled people

The severity of such impact was evaluated by 12 respondents as being of severe nature, 10 as moderate, 3 as minor and 3 as having no impact.

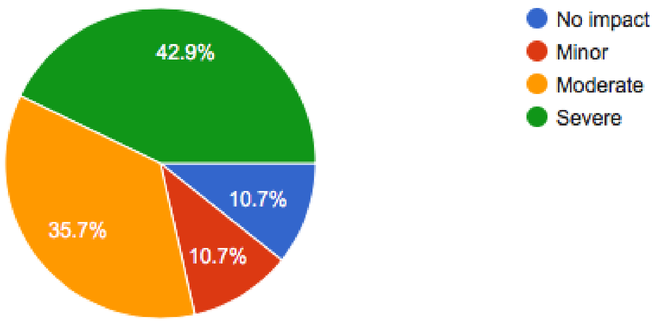

Fig 4b: Severity of the impact

5. **Likelihood of HETs harming human health (i.e., harming physical and psychological well-being) and the severity of such an impact**

The survey respondents, i.e., 19 overwhelmingly thought it likely that HETs might harm human health. 7 respondents said it was unlikely and 2 said it was improbable.

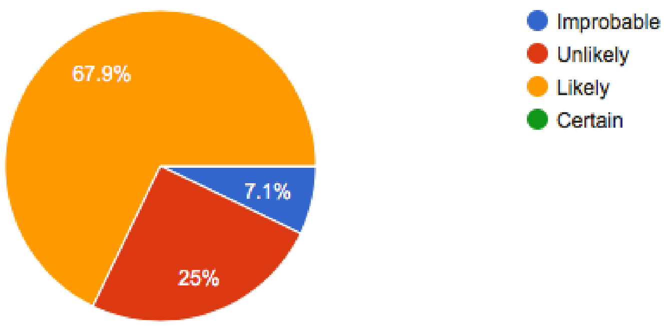

Fig 5a: Likelihood of HETs harming human health

In terms of severity, 11 respondents stated it would be minor, 7 moderate, while 9 thought it might be severe. Only 1 respondent thought there would be no impact.

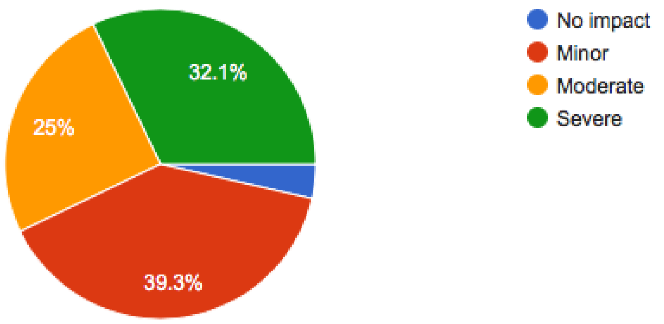

Fig 5b: Severity of the impact

6. Likelihood of HETs creating and/or increasing social inequalities and the severity of such an impact

An overwhelming majority of respondents (20) thought HETs were likely to create and/or increase social inequalities. 6 respondents were certain. Only 1 respondent each thought this was unlikely or improbable.

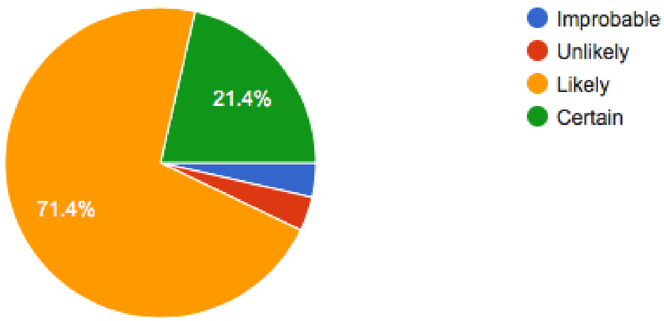

Fig 6a: Likelihood of HETs creating and/or increasing social inequalities

Regarding severity, 13 respondents suggested this impact would be severe, 12 suggested it would be moderate, 2 said it would be minor, while only 1 said there would be no impact.

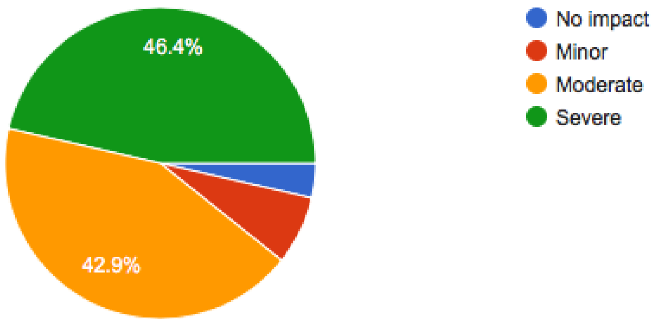

Fig 6b: Severity of the impact

7. Likelihood of HETs causing social disruption and negative impacts on vulnerable populations (e.g., people with mental and/or physical disabilities, people that face persecution and exclusion) and the severity of such an impact

With regard to the likelihood of HETs causing social disruption and negative impacts on vulnerable populations, 12 thought of this as likely and 2 were certain. However, equally 12 thought it unlikely and 2 thought it improbable.

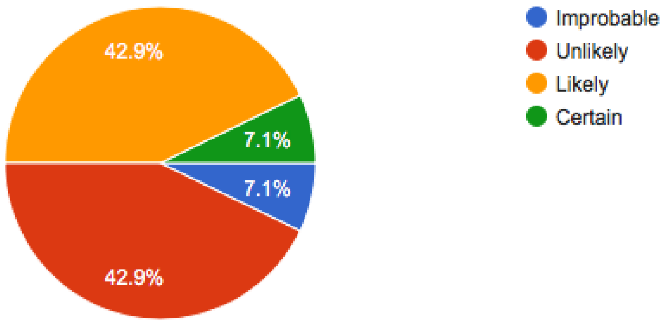

Fig 7a: Likelihood of HETs causing social disruption and negative impacts on vulnerable populations

Out of the 26 that responded to this question, 10 respondents thought the severity would be moderate, and 8 severe. 6 thought the impact would be minor and 2 thought there would be no impact.

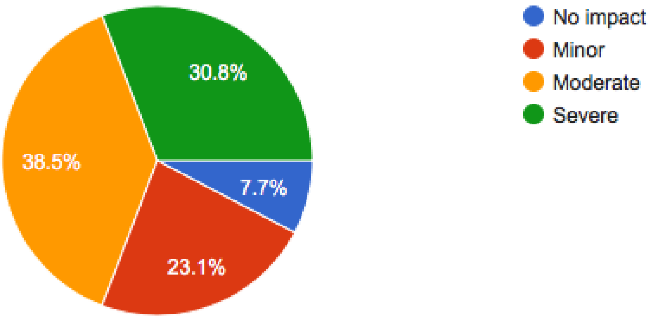

Fig 7b: Severity of the impact

8. Likelihood of HETs causing a burden on economic resources due to increasing human lifespans and abilities and the severity of such an impact

In terms of the likelihood of HETs causing a burden on economic resources, nearly half (13 respondents) thought it likely and 5 were certain. On the other hand, 8 thought it unlikely and 2 thought it improbable.

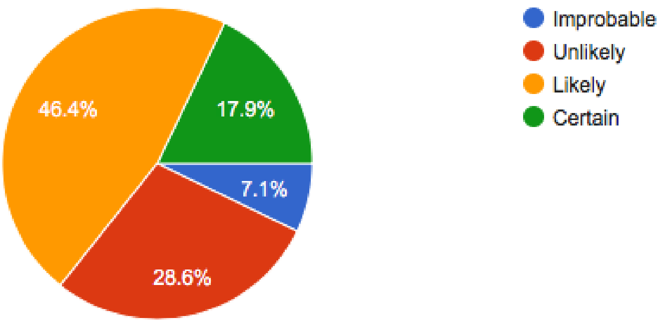

Fig 8a: Likelihood of HETs causing a burden on economic resources

The severity was judged to be moderate by 10, severe by 9, minor by 7 respondents. 2 respondents thought there would be no impact.

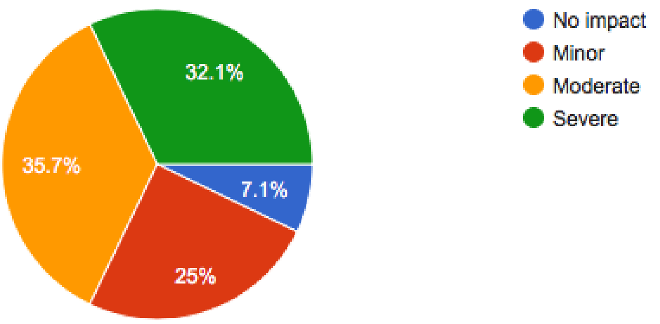

Fig 8b: Severity of the impact

9. Likelihood of HETs increasing unemployment by replacing non-enhanced with enhanced workers and the severity of such an impact

In this regard, opinion is split equally between likely and unlikely. 12 thought it was likely and 4 were certain that HETs might increase unemployment by replacing non-enhanced workers with enhanced workers. 12 respondents thought it unlikely, though none thought it improbable.

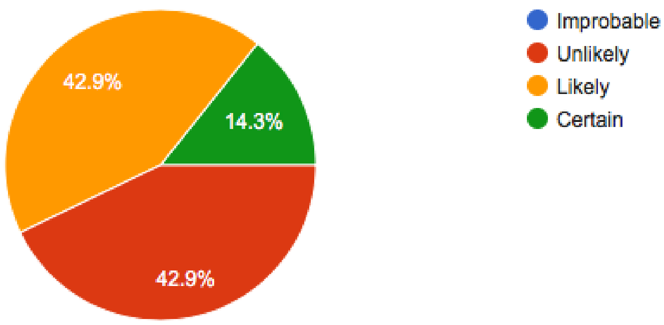

Fig 9a: Likelihood of HETs increasing unemployment by replacing non-enhanced with enhanced workers

In relation to severity, 12 respondents thought the impact would be minor, 8 thought it would be moderate and 8 thought it would be severe. One respondent abstained.

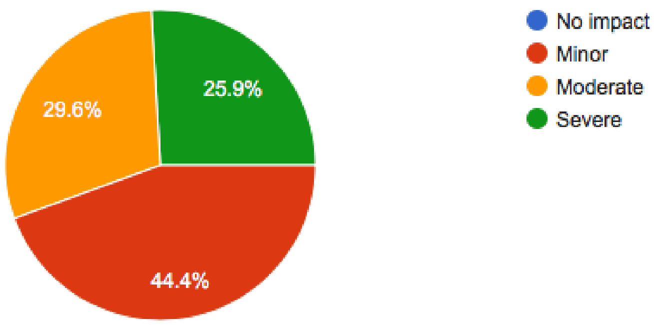

Fig 9b: Severity of the impact

10. Likelihood of HETs perpetuating and/or increasing economic inequalities and the severity of such an impact

The likelihood of HETs to perpetuate and/or increase economic inequalities were determined to be likely by over half the respondents (16) and 7 being certain about this. 4 respondents thought it unlikely while only 1 thought it improbable.

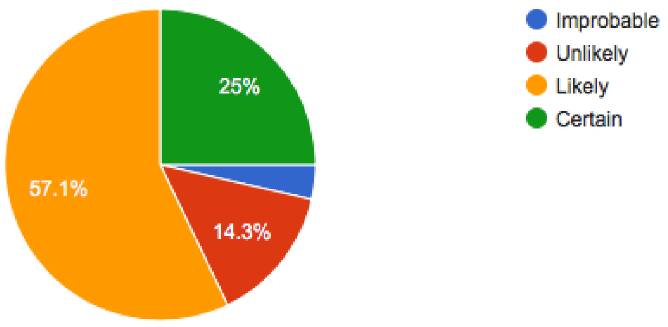

Fig 10a: Likelihood of HETs perpetuating and/or increasing economic inequalities

Regarding the severity of such an impact, half the respondents (13) thought it would be moderate, 9 thought it would be severe, 4 thought the impact would be minor and 1 thought there would be no impact. One respondent abstained.

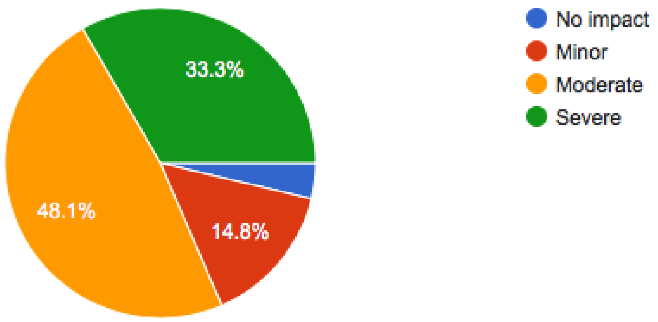

Fig 10b: Severity of the impact

11. Likelihood of HETs adversely affecting international trade relations and the severity of such an impact

Just under half the respondents (12) thought HETs were unlikely to adversely affect international trade relations, while 11 thought it was likely. 4 respondents thought it was improbable. 1 respondent abstained.

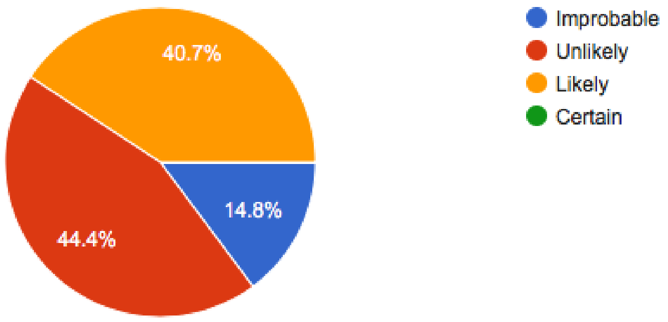

Fig 11a: Likelihood of impact on international trade relations

Over half the respondents (15) thought the severity of such an impact would be minor; 8 thought it would be moderate; 1 thought it would be severe. 2 respondents thought there would be no impact. 2 respondents abstained.

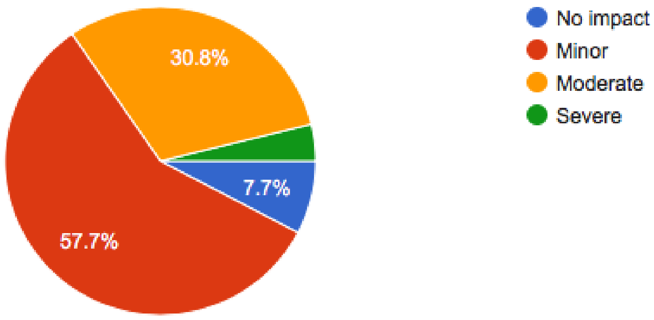

Fig 11b: Severity of the impact

12. Likelihood of HETs having an adverse impact on developing and least-developed nations and the severity of such an impact

Of those who responded to this question, just under half (13) thought it was likely that HETs would have an adverse impact on developing and the least-developed nations. 2 respondents were certain. 11 thought it was unlikely. Two respondents abstained.

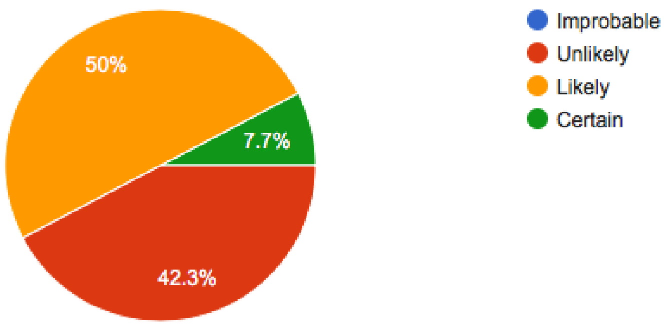

Fig 12a: Likelihood of HETs having an adverse impact on developing and least-developed nations

Of those who responded to this question, 11 respondents thought the impact would be moderate and 3 thought it would be severe. 9 thought it would be minor and 2 said it would have no impact. Three respondents abstained.

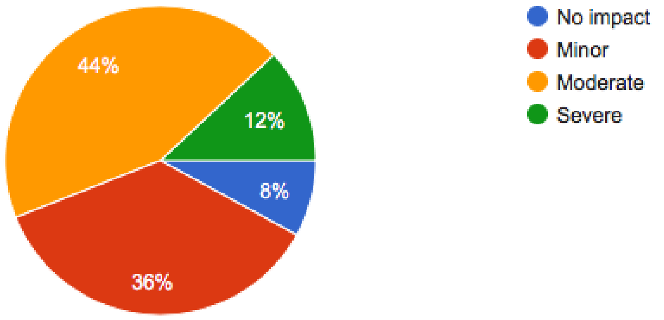

Fig12b: Severity of the impact

13. Likelihood of HETs having an adverse impact on the environment (e.g., creation of technological waste, toxicity) and the severity of such an impact

Slightly over half the respondents (14) said HETs were unlikely to have an adverse impact on the environment. 3 said it was improbable. However, 9 respondents said it was likely, while 2 were certain.

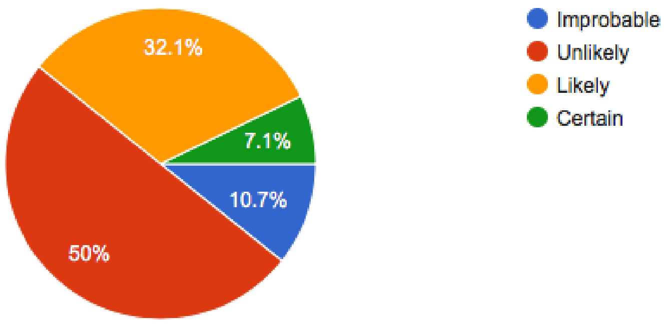

Fig 13a: Likelihood of HETs having an adverse impact on the environment

Regarding severity of this impact, of those who responded to the question, over half (16) said the impact would be minor, 6 said it would be moderate, 2 said it would be severe and 2 said there would be no impact.

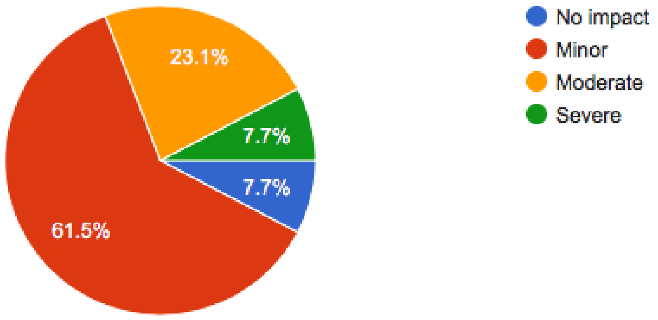

Fig 13b: Severity of the impact