Routledge
Taylor & Francis Group

Journal of Responsible Innovation

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tjri20

Examining funders' roles in responsible research and innovation of medical neurotechnology

Denis Larrivee, Jennifer French, Alberto Antonietti, Zach McKinney, Noeline W. Prins, Joana Soldado-Magraner, Michael J. Young & Laura Y. Cabrera

To cite this article: Denis Larrivee, Jennifer French, Alberto Antonietti, Zach McKinney, Noeline W. Prins, Joana Soldado-Magraner, Michael J. Young & Laura Y. Cabrera (2024) Examining funders' roles in responsible research and innovation of medical neurotechnology, Journal of Responsible Innovation, 11:1, 2381758, DOI: 10.1080/23299460.2024.2381758

To link to this article: https://doi.org/10.1080/23299460.2024.2381758

JOURNAL OF RESPONSIBLE INNOVATION
2024, VOL. 11, NO. 1, 2381758
https://doi.org/10.1080/23299460.2024.2381758

Routledge
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Examining funders' roles in responsible research and innovation of medical neurotechnology

Denis Larrivee[a,b]*, Jennifer French[c]*, Alberto Antonietti[d], Zach McKinney[e], Noeline W. Prins[f], Joana Soldado-Magraner[g], Michael J. Young[h] and Laura Y. Cabrera [i,j]

[a]Mind and Brain Institute, University of Navarra Medical School, Navarrra, Spain; [b]Loyola University Chicago, Chicago, IL, USA; [c]Neurotech Network, St. Petersburg, USA; [d]Department of Electronics, Information, and Bioengineering, Politecnico di Milano, Milano, Italy; [e]IEEE Standards Association – Neurotechnology for Brain-Machine Interfacing, NY, USA; [f]Department of Biomedical Engineering, University of Minnesota, Minnesota, USA; [g]Department of Electrical and Computer Engineering, Department of Biomedical Engineering, Carnegie Mellon University, Pittsburgh, USA; [h]Center for Neurotechnology and Neurorecovery, Department of Neurology, Massachusetts General Hospital and Harvard Medical School, Boston, USA; [i]Center for Neural Engineering, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, USA; [j]Rock Ethics Institute, The Pennsylvania State University, University Park, USA

ABSTRACT

Advances in medical neurotechnology (MNT) have the potential to improve the evaluation and management of conditions of the nervous system. Meanwhile, increasing concern over ethical questions and risks posed by these technologies has prompted various institutional initiatives to examine ethical aspects of their design, development, and deployment. Funding by public agencies, foundations, and private investors plays a fundamental role in driving MNT research and development (R&D). As such, the perspectives and approaches of funders can be central in instilling and shaping the values embedded in MNTs. Responsible development and oversight of MNT requires funders to proactively prioritize the integration of ethical values in MNT. We propose a multiphase design and development process involving discrete institutional norms and organizational practices and explore how this process can enhance the funder role to address ethical challenges and promote values integration in R&D.

ARTICLE HISTORY
Received 20 December 2023
Accepted 15 July 2024

KEYWORDS
Neurotechnology funders; values-based design; medical neurotechnology; translational research; neuroethics; responsible research & innovation

Introduction

The rapid growth of modern neuroscience has catalyzed a rising development in neurotechnologies, which may be defined as engineered systems that record and/or modulate

CONTACT Laura Y. Cabrera lcabrera@psu.edu MSC 491 Pollock Rd Suite W-316 University Park, Pennsylvania 16802-4537, USA
*Denis Larrivee and Jennifer French shared first authorship
Supplemental data for this article can be accessed online at https://10.1080/23299460.2024.2381758.

neural activity, for the purposes of replacing, restoring, enhancing, supplementing, improving, or studying the natural inputs and outputs of the nervous system[1]. While neurotechnologies have been developed and explored for a wide range of research, as well as consumer and medical applications, we define *medical* neurotechnologies (MNTs) as those that interface with the nervous system with an intended use to diagnose, monitor, treat, mitigate, or prevent disease (Stieglitz 2021; Young, Lin, and Hochberg 2021). To date, MNTs have been used or are being developed to address a wide range of neurological and mental health conditions affecting millions worldwide (Apantaku et al. 2022; Bargmann and Newsome 2014; Jorgenson et al. 2015), as well as to advance our knowledge regarding how disorders of the nervous system are caused by electrical, biochemical, and/or biomechanical signaling abnormalities.

Compared to other interventions, MNTs offer unique and complementary advantages in the evaluation or treatment of conditions of the nervous system. MNTs may interface directly with the human nervous system and enable a more direct connection to technical components such as electrodes, computers, or intelligent prostheses (Müller and Rotter 2017). Unlike pharmaceuticals, which are exceptionally difficult to deliver with spatial precision, they have the potential to modulate specific neural circuits and therefore to alter specific brain processes with greater selectivity (Felix 2021). In other cases, MNTs and pharmaceuticals can work in synergy. For example, deep brain stimulation (DBS) for epilepsy may be used in conjunction with traditional antiseizure medications to control seizures, and DBS Parkinson's disease may help to mitigate dyskinesia side-effects of levodopa with adjustable stimulation parameters (Deuschl and Agid 2013).

Many of these technologies with different maturity levels are now available. Some have been used for decades and are part of the common medical practice to diagnose or treat neural pathologies, while others are more recent and remain at the preclinical or clinical trial stage. Current projections indicate that MNT development and use is likely to significantly grow (DeFranco, Rhemann, and Giordano 2020; IEEE BRAIN Neuroethics Framework: Medical 2023).

As MNTs have progressed in complexity and capability, however, concern over the ethical, legal, societal, and cultural implications (ELSCI) of their use has increased (Bianchi et al. 2018; Eberwine and Kahn 2020; Goering et al. 2021; Ienca and Andorno 2017; 2021; Coenen and Stieglitz 2021; Soldado-Magraner et al. 2024). The Presidential Commission report, Gray Matters I (Gutmann and Wagner 2015), for example, cites the potential of neuromodulatory interventions for affecting fundamental human traits such as personality, identity, autonomy, or agency in ways that are qualitatively different from previous interventions. Others question the possible intrusion into key domains of privacy once privileged to thoughts alone (Goering et al. 2021) or the coercive use of such technologies (Ienca 2021), among other issues. Moreover, while the importance of cultural considerations in neurotechnology have been discussed (e.g. Ienca 2021), few explicitly discuss its implications. Following on our work in developing the IEEE BRAIN Neuroethics framework, we are considering cultural implications as an integral domain that considers culturally transmitted values and attitudes toward technology and thus extends beyond other ethical, legal, and societal implications (IEEE BRAIN Neuroethics Framework 2023).

Calls for responsible innovation of technology in response to the burgeoning sophistication and power of modern technologies are not new. The U.S. National Science Foundation, for example, includes criteria for 'broader impacts' in determining research proposals as worth funding and the European Framework Programmes for Research

(Horizon Europe Programme 2021) have a long tradition of awarding research grants on the basis of anticipated impacts (Owen, von Schomberg, and Macnaghten 2021; von Schomberg 2013). In instances, responsible innovation has been linked to broad normative touchpoints, like the quality of life, and economic and social cohesion (von Schomberg 2013). Neurotechnologies have also provoked calls for global guidelines governing their application (Goering et al. 2021) and for extended human rights frameworks (Ienca and Andorno 2017) – for example, via the specification and codification of a new class of 'neurorights' that directly address emerging ethical risks posed by neurotechnologies. While the specificity of these emerging ethical risks exclusively to neurotechnologies remains a topic of debate, the profound ELSCI of emerging neurotechnologies and the need for a proactive multi-stakeholder approach to managing these implications remains clear.

The need to address such concerns is driven by the recognition that a fundamental aspect of MNT applications are the ethical values that need to be preserved as a condition of their use, thus integrating values in the design process becomes a key aspect of the responsible development and use of MNTs. We refer to this process of integrating value into MNTs as a '*values-based*' approach[i] (Cenci and Cawthorne 2020; Friedman 2004; Friedman and Hendry 2019; Manders-Huits and Zimmer 2009; van den Hoven 2013).

A values-based approach can be most effective in institutional settings that are intimately associated with technology genesis, and which are thus capable of directly influencing technology R&D. While there has been growth in support for and inclusion of ethics in neuroscience research, corresponding policy and institutional structures are lacking for MNTs and administered chiefly from regulatory perspectives that focus primarily on safety and risks. At the same time, proposals for broad ethical frameworks (OECD 2019; Owen, von Schomberg, and Macnaghten 2021), are not easily translatable to specific neurotechnology applications.

In light of these considerations, funding entities have the potential to provide a well-suited organizational locus for driving the integration of ethical values into emerging MNTs (Gutmann and Wagner 2015). In public and private settings alike, funding constitutes an essential resource and constraint in the evolution, translation, and maturation of these technologies (Bargmann and Newsome 2014; IEEE BRAIN Neuroethics Framework 2023; Jorgenson et al. 2015;), thus influencing the institutional context in which neurotechnologies are developed from proof-of-concept to full-scale application (Table 1).

Given funders' potential for enhancing the responsible innovation of MNTs, we explore the interplay between a values-based approach and the role and influence of funders in the research, development, and maturation of MNTs. We discuss how a synergy of factors – e.g. the high medical and ethical stakes of nervous system interventions, the progressive evolution in MNT capacities and complexity, and the intimate relation of funding organizations to translational neurotechnology R&D – favor expanding the role of funders to explicitly prioritize the integration of ethical values in these technologies. Particular attention is directed toward mobilizing funder practices and policies to ensure alignment of MNTs with ethical values from inception to application stages.

Roles and influences of funding organizations in values integration

Due to their role in promoting R&D, funders[ii] have developed a variety of oversight structures and mechanisms that have corresponding potential for supporting the

Table 1. Diversity in Funding Oversight of Medical Neurotechnologies.

Type of Funders*	Oversight Constraints on Medical Neurotechnology Design and Translation			Ethics Resourcing Marshalled by Funders
Public vs Private (example)	Determination of Technology Scope/ Type	Technical Disclosure	Financial Disclosure	Typical Source
Government (NSF; NIH; European Commission)	Broad/multimodal	Proposal, prototype, standards	Sourcing/ Quarterly	Publicly funded, Collaborative, Consultative
Foundations (Howard Hughes; Wellcome Trust, Institut Pasteur)	Medium/multimodal	Proposal, prototype	Sourcing/ Quarterly	Collaborative, Consultative
Private Philanthropy (One Mind, Milken Institute)	Narrow/single	Proposal, prototype	Sourcing/ Quarterly	Consultative
Private Equity/Venture Capital	Narrow/single	Proposal, prototype	Sourcing/ Quarterly	Consultative

*We acknowledge that there is no straight forward way to categorize funders. For example, the US tax code/IRS distinguishes only between private foundations and public charities. Beyond the IRS, there are different ways people categorize foundations such as operating vs. non-operating, independent vs. family, etc. There are also various new types of foundations that are being established in creative ways e.g. donor-advised funds. However, for the purpose of this table we aimed to described broad categories as used by the Milken Institute and the Neurotech Reports Market for Neurotechnology (2023).

processes and practices associated with values integration in MNTs (Table 1, Figure 1, Section 3.2.2). Moreover, they have the potential to elicit various modalities of ethics support, from the sourcing of publicly funded entities to collaboration with ethical experts (Collaborative) or simply ethical consultation (Consultative), with some making use of all these approaches.

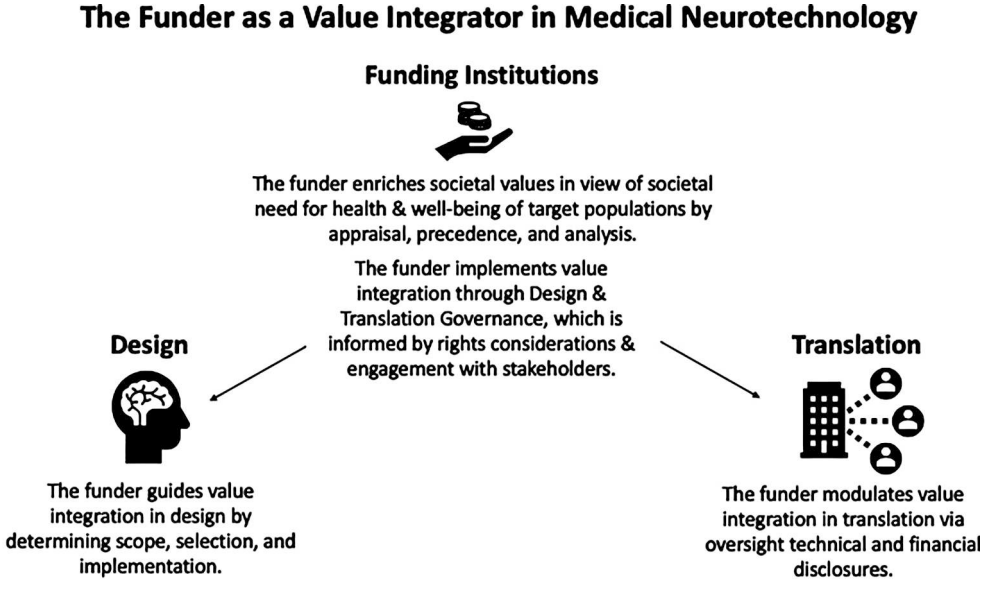

Figure 1. The role of the funder in integrating values in medical neurotechnology.

Types of funders

While heterogeneous, funders of medical neurotechnologies may be generally divided into three classes (Table 1): national health-related government institutions and agencies, charitable foundations, along with nonprofit and for-profit philanthropic institutions, and private equity and venture capital. It is important to note that foundations and philanthropic institutions incorporate a wide number of organizations, and their formation is evolving; however, they are described here in broad categories to understand their roles in the funding landscape. Funders are diverse in their distribution of funding along the technology development lifecycle. Some government or publicly funded institutions, have broad mandates for nervous system disease prevention and treatments, such as, for example, the support of basic research and proof-of-concept studies to de-risk development strategies to attract private sector investment (National Institute of Neurological Disorders and Stroke (NINDS 2021)). Charitable Foundations and Philanthropies may be privately funded or in the form of a public-private partnership. The structure of these organizations tends toward a clear mission and funding pathway but may have more flexibility in the forms of oversight and risk tolerance. Typically, their funding supports a wide spectrum of technology development since it is dependent on the defined mission of the organization. Finally, private funding organizations in the form of either philanthropy or private equity/venture capital tend to invest in the later stages of translational technology development. Like non-profit philanthropies and charitable foundations, these organizations have more flexibility but are driven by a defined mission, goals, and risk profiles outlined. These support organizations also tend to be more risk-averse than the other categories listed.

Values integration in traditional technology funding

Traditionally, many technology funders, including those of MNTs, have identified their role with improving technology capability from the perspective of the economic betterment of society, an objective that became embedded in design (Milbergs 2004). Since improvements in capability were conceived in relation to economic prosperity, economic indices were often used not only to benchmark successful technology innovation but also to assess societal well-being (The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems 2019). Less than a decade ago, for instance, the National Science Foundation cited the linkage between American prosperity that followed WWII and the nation's ability to translate scientific and engineering research discoveries into marketable technologies as a chief funding rationale (Mansfield 1991; Milbergs 2004; National Science Foundation Directorate for Engineering 2010; Tassey 2008). A key incentive for funding, therefore, has been a premise that the pursuit of improved technological prowess would promote both economic and societal well-being, a presumption likely to mask other normative considerations (The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems 2019).

Critiques of a link between technological advance and societal well-being, however, have raised concerns about technology's wider effects on individuals and society (Jonas 1984). MNTs, particularly, raise numerous issues on human health and well-being (Goering et al. 2021; Ienca and Andorno 2017). These concerns have stimulated

the discussion of ethical, legal, and sociocultural issues that are raised by technology advances, including MNTs, among a variety of professional and non-governmental organizations as well as task groups and committees (e.g. OECD 2019; IEEE BRAIN Neuroethics Framework Working Groups).

The funder: A key institutional medium for integration of values

In line with these initiatives, we propose that one way to advance a values-based approach to neurotechnologies R&D is by enhancing institutional oversight. However, not all institutions are suitable for this purpose. Institutions dedicated to exploring the ethical implications of technology, for example, typically do not have oversight roles in technology conception and usually explore the ethical consequences of neurotechnological devices in their application settings, once a technology has matured. Others, such as regulatory institutions, have traditionally dealt with a limited range of ethical issues. In their role of overseeing the compliance of medical technologies, there is relatively little influence on design, and ethical aspects are addressed chiefly in the context of benefit-risk analysis, a consequence of the specific mandate of regulatory institutions. Standard legal frameworks for the evaluation of the safety and effectiveness of medical devices have traditionally focused on medical or health benefits and risks to the user, without particular consideration of risks to other stakeholders (e.g. family and caregivers) or broader ethical or social implications. For example, U.S. Code of Federal Regulations (CFR) statute 21 CFR 860.7(b) states that '*in determining the safety and effectiveness of a device … the Commissioner and classification panels will consider … (3) the probable benefit to health from use of the device weighed against any probable injury or illness from such use*' – but does not explicitly specify the consideration of other types of benefits and risks to stakeholder communities or healthcare systems. However, the importance of identifying and mitigating risks to a broader range of medical device stakeholders is acknowledged by standard ANSI/AAMI/ISO 14971:2019 (Application of Risk Management to Medical Devices), which states that '*the concepts of risk management are particularly important in relation to medical devices because of the variety of stakeholders including medical practitioners, the organizations providing health care, governments, industry, patients and members of the public*' (ANSI/AAMI/ISO 2019). Still other institutions (e.g. federally mandated, commercial oversight agencies like the Federal Trade Commission) limit oversight to commercial reliability and transparency, with only indirect influence on device creation. The challenges faced by these institutions bring to light the opportunity for medical neurotechnology funders to address ethical concerns.

Due to their intimate role in the genesis and development of MNT, funders are well positioned to compel or incentivize the integration of values throughout the development and application of MNTs. MNT funders exercise a key influence in determining the medical scope to be addressed by the neurotechnology. Funders also perform a critical role in governing technology development at key stages, from inception to maturation, overseeing the selection of proposed technologies and guiding the course of their technical translation. Through mechanisms of incentivization, requirement, and financial support, funders can actively promote the integration of ethical values, defining the ethical space within which salient issues could be explored and promoting the design and translational processes necessary for value integration. Funder oversight

from inception through translation to maturation can also help to streamline later regulatory oversight; by encouraging ethical inquiry during the conception and subsequent translational phases of the medical neurotechnology (Rommetveit and van Dijk 2022).

Critically, the role of funders in MNT genesis, e.g. establishing project scope, requires societal input that can help to establish and refine the objectives that funders intend to support. On the one hand, funders of MNT are generally distinguished by a predetermined mission and rationale in response to a distinct medical need. On the other hand, this overall mission is subject to external influences (e.g. research findings and/or economic perspectives), societal needs (e.g. disease prevalence), and societal risk tolerance that affect the immediate context within which the mission objective for funding is shaped. Because the scope for funding is conditioned by these influences, the funder can exercise an essential representational role on behalf of the wider social community, as well as targeted patient populations, to implement these considerations in all stages of technology development. Indeed, motivating value integration is an implicitly recognized social contract that normatively embraces the medical domain and its adjunct alliances with the society they serve (Hessels, van Lente, and Smits 2009; Starr 1982). In view of the general public health mission that the broader medical community participates in, these alliances may be understood to include funder institutions, which enable the provision of medical devices to the clinical profession.

Global norms and their mutual relationship also help provide a legitimate basis for defining the values that research and innovation ought to pursue (von Schomberg 2013), which funders need to promote in their role of overseeing technology genesis.

Values integration in the modern funder landscape

Currently, different types of funders (Table 1) adopt heterogeneous procedures to evaluate ethical aspects of project proposals that are submitted for funding that are generally motivated by overarching national polity. In Europe, for example, the document 'Orientations towards the first Strategic Plan for Horizon Europe', provides a mandate for responsible research and innovation (Horizon Europe Proposal 2021) and emphasizes meeting the normative 'touchpoint' of Sustainable Development Goals (e.g. sustained employment). In the context of research funding, the European Commission also requires a mandatory ethical self-evaluation to be included in funding proposals (Horizon Europe Proposal 2021). On the other hand, the scientific aim of the proposal typically receives evaluation priority and may override ethical considerations in cases deemed critical. Moreover, while the introduction of 'mission-oriented' research, co-designed with stakeholders and citizens, offers the potential for collectively directing and mobilizing responsible innovation toward societal challenges, these remain currently under-activated (Robinson, Simone, and Mazzonetto 2021). For medical devices, the Medical Device Regulation statute 2017/745 (MDR) primarily focuses on regulatory requirements for medical devices, indirectly reinforcing values such as patient safety, quality of care, transparency in the regulatory process, and general ethical values in the development, manufacturing, and marketing of medical devices. A similarly broad approach is that adopted by the General Data Protection Regulation statute 2016/679 (GDPR), which has been promoting and enforcing principles such as privacy, transparency, accountability, and individual rights. These latter statutes provide a general recognition that values integration is a necessary element in MNT

development but lack specificity in application (Cioeta et al. 2022; General Data Protection 2020; Letourneur et al. 2021).

In the U.S, the National Institutes of Health (NIH) has promoted a set of seven guiding principles for ethical research in neuroscience and has introduced ethical overview for some funding mechanisms, requesting investigators to provide a section on neuroethics in addition to that specifically oriented toward human subject protections (Greely et al. 2018). While the NIH initiative affords the opportunity for a general ethics overview, such analysis remains the exception rather than the rule among funding organizations, with many funders not requiring explicit and rigorous consideration of these issues (for a few other examples refer to Table A in the Appendix). Traditionally, and in most cases, neuroscience funders defer to institutional review boards (IRBs – also known as ethics committees (ECs)) as the default mechanism for ethical review of human subjects' research. IRBs/ECs typically apply the general medical and bioethics framework established by the 1979 Belmont Report 43 (US Department Health and Human Services 1979) and the Declaration of Helsinki, centering around the process of informed consent of research participants and based on the basic ethical principles of respect for persons, beneficence, and justice. While these principles can help to provide a basis for informing the consideration and translation of ethical values to medical neurotechnology research and use, they are not structured to ensure technology specific consideration of novel or key ethical issues that may arise in the development of emerging neurotechnologies and it is outside their scope to consider broader ethical considerations and societal impacts. Moreover, key issues, e.g. the privacy and use of research participants' (neuro) data, are typically not clearly specified in informed consent documents.

Challenges of funder mediated values integration

Various factors, however, present challenges for funders to undertake values integration in technology genesis and development.

A core challenge is to integrate values-based design with the technical aspects of neurotechnology creation. Because ethics may be erroneously viewed as a constraint on innovation 44-46, 32 (Birtwistle 2021; The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems 2019; Walker 2016), the relationship between these two constituent aspects of design is a complex one, the resolution of which needs to be overseen by the funder in the design process (Donia and Shaw 2021; Friedman and Henry 2019; Philbeck et al. 2018; van den Hoven 2013). Besides coordinating distinct disciplines to generate cohesiveness in design aspects, there is a need to merge divergent knowledge bases and value systems as they pertain to technical aspects of the technologies. This requires an intensely collaborative development ecology with attendant managerial and teaming challenges (Agre 1997). In their oversight role, therefore, funders should seek to elicit practices that ensure collaborative engagement and prioritization of value considerations. In particular, considering which values are important will depend to a large extent on the funder and the socio-technical context in which MNTs are embedded (For more on this see Section 3.1).

Challenges are also introduced by tensions in value relationships. For example, what counts as health or well-being and which values best prioritize it? Which or to what

extent should a patient suffering from PTSD have certain memories preserved, for instance? Ethical frameworks here can provide moral justification and help to prioritize certain values over others (Bianchi et al. 2018; Grunwald 2001; Skalko and Cherry 2016; The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems 2019). The interrogation of specific values with respect to these frameworks can lead to a more transparent and systematic approach to resolving value tensions (Andorno 2009; 2013; Ienca 2021). There is also tension between technological advance and ethical consideration, as issues of parity are often modified in deference to technology prowess (Prins et al. 2022; Yaghmaei 2018). Because of the nature of their mission, for example, some funders may acquire greater risk latitude in the evolution of technological capability, e.g. Defense Advances Research Projects Agency (DARPA) (Walker 2016).

External factors may also introduce tensions, such as a misalignment between the funder's perception of its mission and socially or economically identified goals (CBInsights 2019). Such tensions can raise questions regarding limits to which the funder's endorsement of values ought to be prioritized for integration. To what extent should the funder be the chief arbiter of societal need? How might conflicts of interest be appraised and resolved?

Guidance for integrating values

Despite the difficulties posed by including values integration within the funder role, we describe here several ways that could assist funders in overcoming these challenges.

Drivers and factors influencing values integration

When considering values integration, funders of medical neurotechnologies must not only confront the deeply ethical nature surrounding intervention within the nervous system (Andorno 2009; Coeckelbergh 2006; Goering et al. 2021; Gutmann and Wagner 2015; Skalko and Cherry 2016) but also accommodate the many contextual features that shape the values integrated into MNTs. These values emerge from policy and normative touchpoints, societal and patient factors, and MNT specific ELSCI considerations.

Policy and Normative Touchpoints: Dominant ethical concerns are frequently raised in the context of broader policy considerations such as human rights frameworks (Ienca and Andorno 2017). Dominant concerns that stimulate ethical consideration can include, for example, unwanted effects on fundamental aspects of human features and behavior, hard-to-predict risks of neurological and psychological impairment in the complex milieu of the brain, and excessive access to private end-user information or undue influence over brain function.

These constitute 'value drivers' because they should be of paramount consideration in the design and use of the neurotechnology (Goering et al. 2021; Ienca 2021; Ienca and Andorno 2017).

ELSCI Considerations: Of lesser, though substantial ethical importance, is a host of other factors that may influence values in design (Agre 1997; Woodhouse and Patton 2004), including community values, professional ethics surrounding the medical use of the device, mission scope and risk latitude, and prospective uses to which the neurotechnology may be put, among many others (Figure 2). While these concerns may

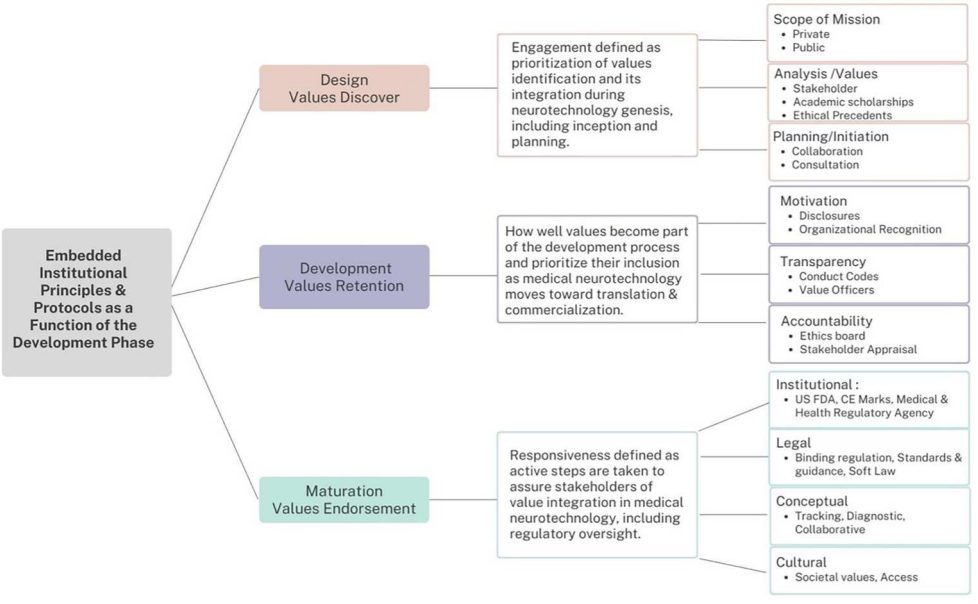

Figure 2. Integrating values in medical neurotechnology in concert with technology evolution, from inception to maturation.

be guided by overarching rights and policy considerations, the specific features can vary, cumulatively contributing to the ethical value, intensity, and manner of expression and affecting which values and how these are to be integrated in an MNT (IEEE BRAIN Neuroethics Framework: Medical 2023). For example, sensing and recording devices present multiple issues, with privacy and data misuse being particularly relevant. Frequently, these arise in the context of the cultural setting in which patient use of the neurotechnology may be proscribed. For example, there is cultural variation in perspectives and meanings given to specific ethical issues such as what it means for a person to have autonomy in a situation, or whether individual autonomy is prioritized over family preferences. As such there is a growing awareness of the need for those involved in the development and implementation of neurotechnology to incorporate awareness and sensitivity to cultural differences in the design process, such as an end-user's community setting, the medical objective of the technology (Starr 1982; Woodhouse and Patton 2004), advocacy interests, and scope of funding, among others. Incorporating cultural sensitivities typically requires proactive engagement with target device users and their communities early and throughout the process of technology development, validation, and implementation.

Institutional practices for values integration

In their oversight role, funders have a unique opportunity to foster values integration during design, development, and maturation of MNTs (Hui, Schatzki, and Shove 2017). Here, we describe institutional norms and practices that funders can promote to assist values integration.

Coordinating institutional principles and practices with technology design

Governing the selection of practices are organizational attitudes essential to value alignment, which constitute institutional normative principles (Figure 2) that both motivate and guide the adoption of practices needed for value integration during each phase (Jacobs and Huldtgren 2021; Pfotenhauer et al. 2021; Smits et al. 2022). Hence, funders can assist value integration during design, development, and application (Hui, Schatzki, and Shove 2016) by emphasizing distinct institutional norms and practices at different stages of technology evolution (Figure 2).

Here, we identify three technology phases: design, development, and maturation[iii], which evoke distinct institutional principles and practices. For each phase the corresponding objective for values integration is shown in Figure 2. Note that most principles are valid for multiple phases but vary in the degree of salience according to phase.

Institutional norms and practices for values identification and retention

Interventional tools for promoting institutional norms and practices – governance through incentivizing, assessing, and resourcing.. Traditionally, funders have had at their disposal several tools (Figure 1) to assist the oversight of research activity, including that of MNT genesis. These tools constitute interventional mechanisms that lay out the scope of research activities and monitor its successful conduct (Hessels, van Lente, and Smits 2009). We propose here that such tools can be employed to optimize values integration in MNTs by eliciting institutional norms and practices through incentivizing, assessing, and providing resources for values integration. For example, the delegation of specific funding contracts and grants that fulfill research and design expectations enables funders to delimit the application objective, performance characteristics, and features that characterize research conduct.

In cases of MNT proposals, the determination of values alignment with MNT scope rests with the funder and is dictated by the funder's choice and use of value criteria (Section 3.1). Use of such criteria can guide the appraisal and selection of an MNT proposal and derives to the funder in its capacity as a representational agent of government policy, rights frameworks, and/or societal values (Section 2.3, 3.1). In many cases, the successful incorporation of ELSC values in MNT research projects can be best achieved not through the implementation of pre-specified operational goals defined by the investigators, but through a collaborative process of inquiry and engagement with the individuals and communities whose rights and integrity are affected by the MNTs under investigation. Thus, in their evaluation of funding proposals, funders should consider not just the implementation of known best practices, but also the applicant's proposed process for patient and community engagement.

In order to assure that selected research activities adhere to the objectives proposed in the application process throughout the duration of research projects, funders traditionally have also had recourse to various means of performance assessment, which has assumed differing formats – e.g. visitations vs disclosures – and assessed differing scientific or monetary and physical standards by various parameters – e.g. financial disclosures, presence of qualified scientific personnel, cumulative scientific data, cited publications, and the like. For funders of MNTs, value alignment is additionally crucial, with key issues involving those of value retention during device translation

and application. Performance assessments for these latter issues require distinct criteria from those used for device performance. Several are described below.

In many instances technology designers have scientific capabilities for innovation but lack resources for identifying and integrating values. In such cases, funders can assist designers in their capacity as value resources. Through funder networks, government liaisons, and working partnerships, funder resources can be embedded in technology genesis and translation to provide input that assures ongoing value integration (Section 3.2.2. below and Table B).

Neuroethics value discovery – bridging normative and societal factors to technology

During the phase of technology inception, funders will need to prioritize promotion of values identification and its alignment with device *design*, a normative principle termed here as *engagement* (Figure 2). Accordingly, in their role as value integrators, funders have an opportunity to actively elicit the undertaking of protocols that help to identify prospective values best aligned with the medical intent of the proposed technology and to promote a conceptual analysis of how these values can manifest in design (Boehner et al. 2005; Cenci and Cawthorne 2020; Jacobs 2020; Nussbaum 2000; Reijers and Gordijn 2019; van Wynsberghe and Robbins 2014).

Dominant ethical concerns may be identified from various formats that have been promoted for consideration of these issues, including human rights frameworks (Andorno 2013; Ienca and Andorno 2017) or consensus statements arrived at by national and international bioethics bodies (Goering et al. 2021). As such, these formats constitute resources useful for identifying key values for MNT prioritization. In conjunction with the interrogation of such resources, moreover, the formation of broader based funder networks or consortia can help to disseminate common considerations across funder organizations. Besides assisting in achieving recognition of key aspects for consideration, e.g. which neural data ought to be privileged or which models of agency ought to be evoked (Nussbaum 2000), the formation of consortia can provide for uniformity in how these aspects are implemented in practice. Their establishment may also help to overcome limitations encountered by some funders, such as available resources; e.g. while public funders typically have access to such white paper documentation, smaller funders may need to be apprised of these resources (Table 1).

When considering ethical concerns having salience for particular classes or examples of MNTs, funders have access to several resources or practices. The IEEE BRAIN Neuroethics Framework document, notably, is constructed to facilitate designer insight to ELSCI issues that are design specific (IEEE BRAIN Neuroethics Framework 2023). This resource pairs ethical issues with classes of MNTs according to the MNT mode of interaction with the nervous system and can help to highlight ELSCI issues most likely to be encountered with a proposed MNT.

Another resource is that of prior studies of clinically approved devices, such as user or case studies. The characterization of an MNT with class specific technical features (e.g. hearing aids, which fall within a class of recording and stimulating MNTs) (Prins et al. 2022), for instance, would help to link the MNT to ethical issues previously examined in such studies and may also illustrate how these issues could be addressed in design.

Among practices that could be implemented are those entailing direct engagement with the principal stakeholders of MNT use, such as patients and medical personnel. The science of patient input and engagement, for example, has been increasingly applied to the area of medical devices and could provide guidance for MNT development. By translating the science of human studies, patient perspectives in the development process can be optimized. In one example, regulators at the U.S. FDA have adopted engagement programs consisting of social scientists, health economists, clinical professionals, patient population representatives, and more that help to inform the development and evaluation process (United States Food and Drug Administration, Center for Devices and Radiological Health 2024). These organizations provide frameworks, rubrics, and models for responsible engagement programs that have been vetted with scientific research. One notable public-private partnership, the Medical Device Innovation Consortium (MDIC), has focused solely on medical device development. While the specific application is that of regulatory science, in application it could be extended to the ideation stage (Benz and Civillico 2017; Gainforth et al. 2021).

Protocols can also be established to assist conceptual analysis by engaging external expertise. For example, the development of ethical review services for neuroscience research has acquired a substantial repertoire of issues that have relevance for neurotechnology and could be made available by funders (Ramos et al. 2019). Collaborative services could be paired with teams of technical and ethical experts having a diverse range of expertise and bring a variety of perspectives to the consultation. The consultation and collaboration model can be extended externally to provide designers ongoing access to a team of ethicists, which can assist during the evolution and translation of the design. The NIH BRAIN initiative, for instance, has embedded ethics support protocols program to foster neuroethics in neuroscience research, monitor ethical issues within funded projects, and facilitate integration of ethics into the supported research, a resource that could be paired with MNT genesis.

Yet other practices include protocol strategies to facilitate value identification from stakeholder reviews, which are widely available (Gutmann and Wagner 2015). These can provide insight into societal and cultural influences, ethical concerns emerging from neuroscience, technology studies, and value issues identified from neurotechnology precedents.

Retaining values during translation and development

Principles of transparency, accountability, and motivation help to make explicit the incorporation and retention of values, to assess how well they become part of the design process, and to prioritize their inclusion as the medical neurotechnology moves toward commercialization (Figure 3). While distinct, these principles function in a complementary and unified fashion to retain and refine the integration of values identified during the design inception phase. Funders can help to promote these principles by incentivizing corresponding practices and monitoring their implementation.

Transparency is here construed as a funder capacity for visualizing the integration of values through device phases, their retention or alteration, and the rationale for such. Transparency protocols thus enable the funder to observe the process of value maintenance during device translation. A key consideration is that technology development must be transparent to a wide range of stakeholders for different reasons (noting that the level of transparency will necessarily be different for each stakeholder); hence, a *transparent*

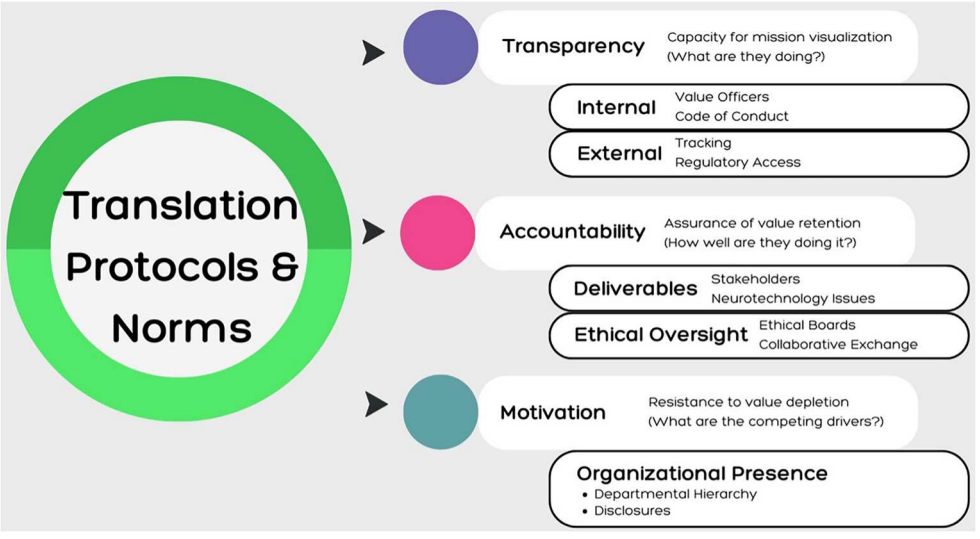

Figure 3. Engagement in the Translation Protocols and Norms. Practices for each principle are distinct, but synergistic in their effect. Some examples of practices are given for each principle.

neurotechnology is one in which it is possible to discover value alignment at needed levels of detail by the funder as well as by external parties. An example of this is the set of practices adopted for the FAIR principles (findability, accessibility, interoperability, and reusability) of neurodata, which has become widely recognized and promoted throughout the neuroscience and neuroinformatics communities (Wilkinson et al. 2016). Adherence to these principles – e.g. through requirements for grantees to use 'common data elements' to share data in large (typically *open*) data repositories (National Library of Medicine 2023) – optimizes transparency of research methods and results, such that they may be understood and applied by the broader scientific and clinical communities.

Additionally, funders can enhance transparency by incentivizing a corporate ecology involving design personnel at various levels of hierarchy (Figure 3). Through specified codes of conduct designers and developers can document design changes during translation that preserve or modify values integration (The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems 2019). Additionally, external review can provide assurance of consistency in internal evaluation e.g. through funder consortia, regulators, society at large, or post-accident investigators. Transparency is essential to arrive at the important long-term goal of accountability, a principle governing practices intended to assure the medical and patient community of values retention.

Accountability practices thus directly complement those of transparency by sustaining value retention as the design process continues to evolve. Research findings as well as debate over technical objectives in relation to ethics alignment, notably, can modify the original design, affecting the degree of integration and/or content of the values outlined at the onset of development.

Practices for accountability implicate an institutional locus for assessing value retention, i.e. one responding to the question 'Who assumes responsibility for assuring that

the values identified during inception have been retained as the MNT continues to evolve?' Traditionally, departments or boards composed of ethics professionals have been charged with overseeing institutional ethical practices. However, the need to relate design features to values integration suggests that this compositional format would require expansion to include professionals with technical proficiency. One format now used for implantable neurostimulation platforms, for example, involves engagement of an external consultation resource comprised of neurological, psychiatric, and ethics professionals (OpenMind 2023). This resource is designed to assist with implementation of later stage clinical studies and to interface with regulatory bodies. A drawback of such external input examples, however, is the need to restrict access to all proprietary information, which can compromise the consideration of some ethical issues.

Motivation practices support those of transparency and accountability by sustaining ethical alignment as an integral aspect of the overall organizational mission. Amidst competing priorities, they serve to balance the prioritization of objectives so that the ethical role is both easily apparent and equally considered (McIntosh, DuBois, and Perlmutter 2022). As a constitutive feature of the institutional mission the ethical role is set in apposition to other major organizational functions with its corresponding need for structural representation and tasking. Within its purview are thus the responsibility for both advancing the ethical aspect of the institutional mission and for assuring that a policy of ethical alignment retains parity with technical and other organizational objectives involved in MNT development.

Accordingly, in its oversight capacity funders can encourage the formation of organizational structures for this role, with suitably designated officials endowed with authoritative parity within the global mission, e.g. the equivalence of ethics, scientific, and financial officers. Access to existing management models can further this process so as to optimize interdepartmental coordination and sustain parity for ethicists monitoring values retention (Kuziemsky et al. 2009). An especially important consideration in ethics prioritization is that of balancing ELSCI values with economic objectives. Financial reward has been an especially dominant incentive motivating inception and development that frequently overshadows other priorities. Access to financial disclosure practices, for instance, could help to reveal funding allocation and provide a tool for highlighting whether ethical concerns are prioritized during technology translation.

Endorsing values integration for medical neurotechnology maturation. Ultimately, the funder should provide for the endorsement of the technology in its mature form by eliciting an indication that the values identified during the discovery process have been integrated in the MNT. Practices that provide this indication fulfill the normative objective of the principle we term *Responsiveness.* Responsiveness can entail many aspects, but together these aspects imbue the funder with an ethical imperative to assure the greater community that the values identified at design inception will be retained when the neurotechnology is used in its clinical setting; hence, the norm is characterized by the funder's self-initiated responsivity to societal value (Reijers and Gordijn 2019).

Protocols at this stage can entail the addressing of statutory requirements in preparation for regulatory overview, such as binding regulations, soft law, or standards, but should also extend beyond legally defined statutes to include, for example, issues of cultural sensitivity,

post-approval oversight, such as tracking values intent during application, and institutional reporting. In practice, such protocols could include funders' collaboration with regulatory advisory boards (e.g. FDA advisory committees) to identify and promote consideration of key ethical issues. Regulators could be engaged at early intervals to develop and execute testing of design features that address these issues, with ongoing collaboration through the compliance and application period. Analogous partnerships with the public sector currently adopt a collaborative community format that could be adapted for use with regulatory agencies (Kuehn 2021). Similar formats could also be adopted with societal or public stakeholders identified during the device inception phase. Such communities are characterized as ongoing forums where private – and public-sector members work together on medical device challenges to achieve common objectives and outcomes. Membership is comprised of interested stakeholders, e.g. patient advocates, health care professionals, and federal agencies, among others, and can exist indefinitely, producing deliverables as needed (Kuehn 2021).

Conclusion

There is increasing recognition that medical neurotechnologies should embed ethical and social values by design (Goering et al. 2021; Ienca 2021; Owen, von Schomberg, and Macnaghten 2021; The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems 2019). This recognition is predicated on a societal interest in overseeing a technology that has grown significantly in complexity and invasiveness and can exert a profound influence over the end-users' well-being. Our proposal of a funder role in prioritizing value integration in medical neurotechnology is consistent with these wider efforts for responsible innovation involving the integration of value in new and powerful forms of technology.

Despite the awareness of this need there is current uncertainty over the organizational form such oversight should assume and how it can most effectively be administered. We propose here that funding institutions can play a key role in value integration, due to their unique proximity to the design process, the ability to guide resources, and embedded oversight capacities. Indeed, funders often bear responsibility for the studies and data findings that serve as the basis for funding initiatives. Such tasking places funders in the unique position to undertake initiatives that respond to these medical as well as societal needs.

While the undertaking of value integration faces several challenges – e.g. managing the intensity of collaborative interaction between funder and technical professionals implicit in promoting values, reconciling values hierarchies and innovation constraints, and constructing interinstitutional consensus – funders can manage these challenges by crafting policies and practices coordinated with the technical constraints imposed by neurotechnology creation and grounded in institutional principles that prioritize ethical and societal concerns, such as those discussed here. In line with this proposal, we suggest that funders can promote responsible medical neurotechnology innovation by undertaking the following:

- Assess the ethical landscape, especially global and national policy
- Support and guide neuroethics value discovery with resource investment
- Engage multi-stakeholder and diverse societal input in establishing value prioritization
- Sustain value retention through practices that prioritize and incentivize ethics presence and exposure

· Elicit wider scale funder partnerships for consensus building and resource sharing
· Exercise stewardship in response to application-level societal and patient concerns

In examining the ethical frontier and capacity building among funding agencies, there are several areas ripe for further development, including establishing guidelines for required professional expertise or the developing of ethical frameworks addressed to medical neurotechnology genesis and implementation. Medical neurotechnology funding entities currently provide limited but increasing guidance to engineers, developers, and other stakeholders in the form of resources for ethical considerations (Appendix: Table A, B). Varied protocol strategies have been implemented, which may include ethical internships, consultative arrangements, or information-based resourcing (Appendix Table B). Given the progressive advances in neuroscience research and neurotechnology development, funders should encourage, promote, and coordinate value integration in these and emerging domains to ensure that innovation and ethical alignment retain equal stature in the creation of MNTs.

Acknowledgements

We thank other members from the IEEE BRAIN Neuroethics Medical Working group for their feedback on earlier drafts. We thank the IEEE BRAIN for their support to publish this article. We also thank Khara Ramos for her comments on funder roles in integrating ethics in medical neurotechnologies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Laura Y. Cabrera http://orcid.org/0000-0002-6220-7096

References

Agre, Philip E. 1997. *Toward a critical technical practice: Lessons learned in trying to reform. AI bridging the Great Divide: Social science, technical systems, and cooperative work*. Hillsdale, NJ: Erlbaum Publishing.

Andorno, Roberto. 2009. "Human dignity and human rights as a common ground for a global bioethics." *Journal of Medicine and Philosophy* 34 (3): 223–240. https://doi.org/10.1093/jmp/jhp023.

Andorno, Roberto. 2013. "The dual role of human dignity in bioethics." *Medicine, Health Care and Philosophy* 16 (4): 967–973. https://doi.org/10.1007/s11019-011-9373-5.

ANSI/AAMI/ISO. 2019. "Medical Devices - Application of Risk Management To Medical Devices" ANSI/AAMI/ISO 14971:2019. Accessed 14 April, 2024. https://webstore.ansi.org/standards/aami/ansiaamiiso149712019?psafe_param = 1&gad_source = 1&gclid = CjwKCAjw_e2wBhAEEiwAyFFFo75Ac4fnCrA79Fp3-OUJ0bjXEAV14FDQiwJ7vNudb6gGomUy8KODQBoCYusQAvD_BwE.

Apantaku, Glory, Magda Aguiar, K. Julia Kaal, Patrick J. McDonald, Mary B. Connolly, Viorica Hrincu, Judy Illes, and Mark Harrison. 2022. "Understanding attributes that influence physician and caregiver decisions about neurotechnology for pediatric drug-resistant epilepsy: a formative

qualitative study to support the development of a discrete choice experiment." *The Patient - Patient-Centered Outcomes Research* 15 (2): 219–232. https://doi.org/10.1007/s40271-021-00544-w.

Bargmann, Cornelia, and William Newsome. 2014. "BRAIN 2025: A scientific vision, final report of the ACD BRAIN working group."Accessed 14 April, 2024. https://acd.od.nih.gov/documents/reports/06052014report-BRAIN.pdf.

Benz, Heather L., Eugene F. Civillico. 2017. "Neuroprosthetics and the science of patient input." *Experimental Neurology*. 287:486-491

Bianchi, Diana W., Judith A. Cooper, Joshua A. Gordon, Jill Heemskerk, Richard Hodes, George F. Koob, Walter J. Koroshetz, et al. 2018. "Neuroethics for the National Institutes of Health BRAIN Initiative." *The Journal of Neuroscience* 38 (50): 10583–10585. https://doi.org/10.1523/JNEUROSCI.2091-18.2018.

Birtwistle, Michael. 2021. "Addressing Barriers to Responsible Innovation." *Responsible Technology Adoption Unit Blog*. December 17, 2021. https://cdei.blog.gov.uk/2021/12/17/addressing-barriers-to-responsible-innovation/.

Boehner, Kirsten, Shay David, Joseph J. Kaye, and Phoebe Sengers. 2005. "Critical Technical Practice as a Methodology for Values in Design." *CHI 2005 Workshop on Quality, Values, and Choices*, 2–7.

CBInsights 21. 2019. "Neurotech Startups To Watch: Brain-Machine Interfaces, Implantables, And Neuroprosthetics." Accessed: April 14, 2024. https://www.cbinsights.com/research/neurotech-startups-to-watch/.

Cenci, Alessandra, and Dylan Cawthorne. 2020. "Refining value sensitive design: A (capability-based) procedural ethics approach to technological design for well-being." *Science and Engineering Ethics* 26 (5): 2629–2662. https://doi.org/10.1007/s11948-020-00223-3.

Cioeta, R., A. Cossu, E. Giovagnoni, M. Rigoni, and P. Muti. 2022. "A new platform for post-marketing surveillance and real-world evidence data collection for substance-based medical devices." *Frontiers in Drug Safety and Regulation* 2. https://doi.org/10.3389/fdsfr.2022.992359.

Coeckelbergh, Mark. 2006. "Regulation or responsibility? Autonomy, moral imagination, and engineering." *Science, Technology, & Human Values* 31 (3): 237–260. https://doi.org/10.1177/0162243905285839.

Coenen, C., and T. Stieglitz. 2021. "Neurotech-Ethics: Suggestions for the Way Forward," 2021 *10th International IEEE/EMBS Conference on Neural Engineering (NER)*, Italy, 2021, pp. 639-642. https://doi.org/10.1109/NER49283.2021.9441374

DeFranco, Joseph, Maureen Rhemann, and James Giordano. 2020. "The Emerging Neurobioeconomy: Implications for National Security." *Health Security* 18 (4): 267–277. https://doi.org/10.1089/hs.2020.0009.

Deuschl, Günther, and Yves Agid. 2013. "Subthalamic neurostimulation for Parkinson's disease with early fluctuations: balancing the risks and benefits." *The Lancet Neurology* 12 (10): 1025–1034. https://doi.org/10.1016/S1474-4422(13)70151-0.

Donia, Joseph, and James A. Shaw. 2021. "Ethics and values in design: A structured review and theoretical critique." *Science and Engineering Ethics* 27: 57. https://doi.org/10.1007/s11948-021-00329-2.

Eberwine, James, and Jeffrey Kahn. 2020. "The BRAIN Initiative and Neuroethics: Enabling and Enhancing Neuroscience Advances for Society." *AJOB neuroscience* 11 (3): 135–139. https://doi.org/10.1080/21507740.2020.1778121.

Felix, Tiago R. 2021. "The rise of neurotech devices and the moment of truth for the pharma industry." *Drug Discovery World*. February 26, 2021. https://www.ddw-online.com/the-rise-of-neurotech-devices-and-the-moment-of-truth-for-the-pharma-industry-9891-202102/.

Friedman, Batya. 2004. "Value sensitive design." In *Berkshire encyclopedia of human-computer interaction*, edited by W. S. Bainbridge, 769–774. Great Barrington, MA: Berkshire Publishing Group.

Friedman, B., and D. G. Hendry. 2019. *Value Sensitive Design: Shaping Technology with Moral Imagination*. Cambridge, MA: The MIT Press.

Gainforth, Heather L., Femka Hoekstra, Rhyann McKay, Chris B. McBride, Shane N. Sweet, Kathleen A. Martin Ginis, Kimberly Anderson, John Chernesky, Tara Clarke, Susan Forwell, Jocelyn Maffin, et al. 2021. "Integrated Knowledge Translation Guiding Principles for Conducting and Disseminating Spinal Cord Injury Research in Partnership." *Archives of Physical Medicine and Rehabilitation.* 102(4):656-663.

General Data Protection. 2020. General Data Protection Regulation (GDPR)." Accessed 04/14/2024. https://gdpr.eu/tag/gdpr/.

Goering, Sara, Eran Klein, Laura Specker Sullivan, Anna Wexler, Blaise Agüera, Y. Arcas, Guoqiang Bi, et al. 2021. "Recommendations for Responsible Development and Application of Neurotechnologies." *Neuroethics* 14 (3): 365–386. https://doi.org/10.1007/s12152-021-09468-6.

Greely, Henry T., Christine Grady, Khara M. Ramos, Winston Chiong, James Eberwine, Nita A. Farahany, L. Syd,, et al. 2018. "Neuroethics Guiding Principles for the NIH BRAIN Initiative." *The Journal of Neuroscience* 38 (50): 10586–10588. https://doi.org/10.1523/JNEUROSCI.2077-18.2018.

Grunwald, A. 2001. "The application of ethics to engineering and the engineer's moral responsibility: perspectives for a research agenda." *Science and Engineering Ethics* 7 (3): 415–428. https://doi.org/10.1007/s11948-001-0063-1.

Gutmann, Amy, James W. Wagner, et al. 2015. *Gray Matters Topics at the Intersection of Neuroscience, Ethics, and Society.* Washington, DC: Presidential Commission for the Study of Bioethical Issues.

Hessels, Laurens K, Harro van Lente, and Ruud Smits. 2009. "In search of relevance: The changing contract between science and society." *Science and Public Policy* 36:387–401. https://doi.org/10.3152/030234209X442034.

Horizon Europe Programme. 2021. The EU Research and Innovation Programme. European Union/European Commission. https://commission.europa.eu/research-and-innovation_en.

Hui, Allison, Theodore Schatzki, and Elizabeth Shove. 2017. *The Nexus of practices: Connections, constellations, practitioners.* Oxfordshire: Taylor and Francis.

IEEE BRAIN. 2023. "IEEE BRAIN Neuroethics Framework: Medical." Accessed April 14, 2024. https://brain.ieee.org/publications/ieee-neuroethics-framework/ieee-neuroethics-framework-medical/.

The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems. 2019. "Ethically Aligned Design: A Vision for Prioritizing Human Well-being with Autonomous and Intelligent Systems." Accessed April 14, 2024. https://standards.ieee.org/content/ieee-standards/en/industry-connections/ec/autonomous-systems.html.

Ienca, Marcello. 2021. "On Neurorights." *Frontiers in Human Neuroscience* 15:701258. https://doi.org/10.3389/fnhum.2021.701258.

Ienca, Marcello, and Roberto. Andorno. 2017. "Towards new human rights in the age of neuroscience and neurotechnology." *Life Sciences, Society and Policy* 13 (1): 5. https://doi.org/10.1186/s40504-017-0050-1.

Jacobs, Naomi. 2020. "Capability Sensitive Design for Health and Wellbeing Technologies." *Science and Engineering Ethics* 26 (6): 3363–3391. https://doi.org/10.1007/s11948-020-00275-5.

Jacobs, Naomi, and Alina. Huldtgren. 2021. "Why value sensitive design needs ethical commitments." *Ethics and Information Technology* 23:23–26. https://doi.org/10.1007/s10676-018-9467-3.

Jonas, Hans. 1984. *The Imperative of Responsibility. In Search of an Ethics for the Technological Age.* London: University of Chicago Press.

Jorgenson, Lyric A., William T. Newsome, David J. Anderson, Cornelia I. Bargmann, Emery N. Brown, Karl Deisseroth, John P. Donoghue, et al. 2015. "The BRAIN Initiative: developing technology to catalyse neuroscience discovery." *Philosophical Transactions of the Royal Society B: Biological Sciences* 370:20140164. https://doi.org/10.1098/rstb.2014.0164.

Kuehn, Bridget M. 2021. "Collaborative Communities" Tackle Device Development Challenges." *JAMA* 326 (11): 1000. https://doi.org/10.1001/jama.2021.15589.

Kuziemsky, Craig E., Elizabeth M. Borycki, Mary Ellen Purkis, Fraser Black, Michael Boyle, Denise Cloutier-Fisher, Lee Ann Fox, et al. 2009. "An interdisciplinary team communication framework and its application to healthcare 'e-teams' systems design." *BMC Medical Informatics and Decision Making* 9:43. https://doi.org/10.1186/1472-6947-9-43.

Letourneur, D., K. Joyce, C. Chauvierre, Y. Bayon, and A. Pandit. 2021. "Enabling medtech translation in academia: redefining value proposition with updated regulations." *Advanced Healthcare Materials* 10 (1): 2001237. https://doi.org/10.1002/adhm.202001237.

Manders-Huits, Noemi, and Michael Zimmer. 2009. "Values and pragmatic action: The challenges of introducing ethical intelligence in technical design communities." *The International Review of Information Ethics* 10:37–44. https://doi.org/10.29173/irie87.

Mansfield, Edwin. 1991. "Academic Research and Industrial Innovation." *Research Policy* 20:1–12. https://doi.org/10.1016/0048-7333(91)90080-A.

McIntosh, Tristan, James M. DuBois, and Joel S. Perlmutter. 2022. "Ethical Challenges in the Commercialization of Neurotechnology: Contending with Competing Priorities." *AJOB Neuroscience* 13 (1): 60–62. https://doi.org/10.1080/21507740.2021.2001083.

Milbergs, Egils. 2004. *Measuring innovation for national prosperity."Center for Accelerating Innovation*. Washington: United States.

Müller, O., and S. Rotter. 2017. "Neurotechnology: Current Developments and Ethical Issues." *Front Syst Neurosci.* 11:93. https://doi.org/10.3389/fnsys.2017.00093.

National Institute of Neurological Disorders and Stroke (NINDS). 2021. "Strategic Plan, 2021-2026 Investing in the Future of Neuroscience" Accessed: 04/14/2024. https://www.ninds.nih.gov/about-ninds/strategic-plans-evaluations/strategic-plans/ninds-strategic-plan-and-priorities.

National Library of Medicine. "Use of CDEs Supports the NIH Data Management and Sharing Policy." March 25, 2023. https://cde.nlm.nih.gov/home.

National Science Foundation Directorate for Engineering. 2010. "The Role of the National Science Foundation in the Innovation Ecosystem." Accessed April 14, 2024. https://www.nsf.gov/attachments/117873/public/InnovationEcosystem-NSF.pdf.

Nussbaum, Martha C. 2000. *Women and human development: The capabilities approach*. New York: Cambridge University Press.

OECD. 2019. "Recommendation on Responsible Innovation in Neurotechnology." Accessed April 14, 2024. https://www.oecd.org/science/recommendation-on-responsible-innovation-in-neurotechnology.htm.

Open Mind. n.d. "Open Mind: Building frameworks for responsible neuromodulation." Accessed April 14, 2024. https://openmind-consortium.github.io.

Owen, Richard, Rene von Schomberg, and Phil Macnaghten. 2021. "An unfinished journey? Reflections on a decade of responsible research and innovation." *Journal of Responsible Innovation* 8 (2): 217–233. https://doi.org/10.1080/23299460.2021.1948789.

Pfotenhauer, Sebastian M., Nina Frahm, David Winickoff, David Benrimoh, July Illes, Gary Marchant. 2021. "Mobilizing the private sector for responsible innovation in neurotechnology." *Nature Biotechnology.* 39(6):661–664. https://doi.org/10.1038/s41587-021-00947-y.

Philbeck, Thomas, Nicholas Davis, Anne Marie, and E. Larsen. 2018. "Values, ethics, and innovation rethinking technological development in the fourth industrial revolution." *World Economic Forum.* Accessed April 14, 2024. https://www3.weforum.org/docs/WEF_WP_Values_Ethics_Innovation_2018.pdf.

Prins, Noeline W., Rebecca Monteleone, Joana Soldado-Magraner, Joanne E. Nash, Michale J. Young, and Laura Cabrera. 2022. "Reexamining the ethical, legal, social, and cultural implications for cochlear implants through a novel neuroethics framework." *In 2022 IEEE International Symposium on Technology and Society (ISTAS)* 1:1–6. https://doi.org/10.1109/ISTAS55053.2022.10226644.

Ramos, Khara M., Christine Grady, Henry T. Greely, Winston Chiong, James Eberwine, Nita A. Farahany, L. Syd, et al. 2019. "The NIH BRAIN Initiative: Integrating Neuroethics and Neuroscience." *Neuron* 101 (3): 394–398. https://doi.org/10.1016/j.neuron.2019.01.024.

Reijers, Wessel, and Bert Gordijn. 2019. "Moving from value sensitive design to virtuous practice design." *Journal of Information, Communication and Ethics in Society* 17 (2): 196–209. https://doi.org/10.1108/JICES-10-2018-0080.

Robinson, Douglas K.R., Angela Simone, and Marzia Mazzonetto. 2021. "RRI legacies: co-creation for responsible, equitable and fair innovation in Horizon Europe." *Journal of Responsible Innovation* 8 (2): 209–216. https://doi.org/10.1080/23299460.2020.1842633.

Rommetveit, Kjetil, and Niels van Dijk. 2022. "Privacy engineering and the techno-regulatory imaginary." *Social Studies of Science* 52 (6): 853–877. https://doi.org/10.1177/03063127221119424.

Skalko, John, and Mark J. Cherry. 2016. "Bioethics and Moral Agency: On Autonomy and Moral Responsibility." *Journal of Medicine and Philosophy* 41 (5): 435–443. https://doi.org/10.1093/jmp/jhw022.

Smits, Merlijn, Geke D. S. Ludden, Ruben Peters, Sebastian J. H. Bredie, Harry van Goor, and Peter-Paul Verbeek. 2022. "Values that Matter: A New Method to Design and Assess Moral Mediation of Technology." *Design Issues* 38 (1): 39–54. https://doi.org/10.1162/desi_a_00669.

Soldado-Magraner, J. E., Antonietti, A., French, J., Higgins, N., Young, M., Larrivee, D., Monteleone, R. 2024. "Applying the IEEE BRAIN neuroethics framework to intra-cortical brain-computer interfaces". *Journal of Neural Engineering.* 21, 0022001. https://doi.org/10.1088/1741-2552/ad3852

Starr, Paul. 1982. "*The Social Transformation of American Medicine: The Rise of a Sovereign Profession and the Making of a Vast Industry*." *Basic Books* 514: 592.

Stieglitz, T. 2021. "Why Neurotechnologies? About the Purposes, Opportunities and Limitations of Neurotechnologies in Clinical Applications." *Neuroethics.* 14, 5–16. https://doi.org/10.1007/s12152-019-09406-7.

Tassey, Gregory. 2008. "Globalization of technology-based growth: the policy imperative." *The Journal of Technology Transfer* 33:560–578. https://doi.org/10.1007/s10961-008-9092-0./.

United States Department of Health and Human Services. 1979. "The Belmont Report" Accessed April 14, 2024. https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/read-the-belmont-report/index.html.

United States Food and Drug Administration, Center for Devices and Radiological Health. 2024. "Division of Patient-Centered Development" U.S. FDA. Accessed: April 14, 2024. https://www.fda.gov/about-fda/center-devices-and-radiological-health/division-patient-centered-development.

van den Hoven, J. 2013. "Value Sensitive Design and Responsible Innovation." In *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*, edited by R. Owen, J. Bessant, and M. Heintz, 75–83. Chichester: John Wiley & Sons.

van Wynsberghe, Aimee, and Scott Robbins. 2014. "Ethicist as designer: A pragmatic approach to ethics in the lab." *Science and Engineering Ethics* 20 (4): 947–961.

von Schomberg, Rene. 2013. "*A Vision of Responsible Research and Innovation*." In *Responsible Innovation*, edited by Richard Owen, John Bessant, and Maggy Heintz, 51–74. West Sussex: John Wiley and Sons. https://doi.org/10.1002/9781118551424.ch3

Walker, M. 2016. "Innovation at DARPA." Institutional Public Distribution Statement. Accessed April 14, 2024. https://www.darpa.mil/attachments/DARPA_Innovation_2016.pdf.

Wilkinson, Mark D., Michel Dumontier, IJsbrand Jan Aalbersberg, Gabrielle Appleton, Myles Axton, Aerie Baak, Niklas Blomber, Jan-Willem Boiten, Luiz Bonino da Silva Santos, Philip E. Bourne, Jildau Bouwman, et al., 2016. "The FAIR guiding principles for scientific data management and stewardship." Scientific Data. 3:160018.

Woodhouse, Edward and Jason W. Patton. 2004. "Design by society: Science and technology studies and the social shaping of design." *Design Issues*, *20*(3): 1–12. https://doi.org/10.1162/0747936041423262.

Yaghmaei, Emad. 2018. "Responsible research and innovation key performance indicators in industry." *Journal of Information, Communication and Ethics in Society* 16 (2): 214–234. https://doi.org/10.1108/JICES-11-2017-0066.

Young, Michael, David J. Lin, and Leigh R. Hochberg. 2021. "Brain-Computer Interfaces in Neurorecovery and Neurorehabilitation." *Seminars in Neurology* 41 (2): 206–216.