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Responsible innovation in neurotechnology enterprises

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Foreword

This document is the result of analytical work on the opportunities and challenges of implementing responsibility frameworks into neurotechnology translation at major brain research initiatives and in the private sector. The report draws on: (1) the discussion at the BNCT workshop "Minding Neurotechnology: delivering responsible innovation for health and well-being", 6-7 September 2018, Shanghai, People's Republic of China (referred to the "Shanghai Workshop" hereafter); and (2) commentaries by workshop participants.

The Shanghai Workshop was focused on exploring some of the unique ethical, legal, and policy challenges raised by health-related applications of brain science and its integration into cutting edge neurotechnologies. One key aim of this workshop was to provide a forum for innovators to discuss strategies for delivering responsible innovation in neurotechnology for health applications.

The BNCT Project "Neurotechnology and Society" (Programme of Work and Budget 2017-2018) and the Shanghai Workshop were supported by the Korea Legislation Research Institute (KLRI), Korea, and by The Kavli Foundation, USA.

The workshop was supported and hosted by the China National Center for Biotechnology Development, Beijing, People's Republic of China, and by the Tongji University School of Medicine, Shanghai, People's Republic of China.

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Key messages

Novel neurotechnology offers significant potential for the promotion of health[1] and economic growth. Spearheaded by large national and international flagship initiatives in brain science and fuelled by a clear medical need, research both in the public and private sector has made considerable strides towards novel neurotechnology, services and markets. At the same time, neurotechnology raises a range of unique ethical, legal, and policy questions that potential business models will have to address. These questions include issues of (brain) data privacy, the prospects of human enhancement, the regulation and marketing of direct-to-consumer devices, the vulnerability of cognitive patterns for commercial or political manipulation, and new inequalities in use and access. While some of these issues are shared by other technology domains (e.g. gene editing or artificial intelligence (AI)), neurotechnology is exceptional because of the close connection between brain and cognition to human identity, agency, and accountability. Yet, it is also an extremely diverse field of research and commercial activity, which requires a custom-tailored approach to regulation based on the particular applications under consideration – e.g. their scope (e.g., invasive, non-invasive), types of data produced, and target audiences envisioned.

While approaches for fostering "responsible innovation" have become more common in the public sector, private sector frameworks are only beginning to emerge. The 2018 OECD Shanghai Workshop "Minding neurotechnology: delivering responsible innovation for health and well-being" brought together more than 120 leaders from 12 countries from government, companies, academia, venture capital, and insurance companies to shed light on the benefits, challenges, and options of strengthening responsible innovation in the private sector. The workshop yielded a number of important lessons about the interactions between emerging neurotechnology innovators, policy makers, and civil society, both on what is happening already and what is needed. It also revealed a number of important insights into the potential role of the private sector for responsible innovation more generally beyond neurotechnology. Among the key messages are:

- **It is time to re-think governance of neurotechnology.** Brain research in the public and private sector has made considerable progress towards novel neurotechnology applications, both for clinical and non-clinical use. Innovators are receiving significant public and media attention, occasionally mixing issues around neurotechnology innovation with controversies in adjacent domains (such as gene editing and AI). A highly heterogeneous international landscape of innovation practices, regulation of nascent markets, and *de-facto* standards (e.g. through industry self-regulation) is rapidly emerging, which creates uncertainty among public and private sector actors.
- **Stakeholders in the public and private sector are looking for guidance.** There is an urgent need to develop shared frameworks for how novel neurotechnology and associated data are used. New governance mechanisms will likely be required to address how these technologies challenge our understanding of human agency, identity, and the boundaries of normal human capacity; how to identify and

[1] Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

anticipate the broader impact of neurotechnology on society; and how the potential of novel neurotechnology is communicated to the public to both inform and to avoid hype. Moreover, guidance will be needed on how to conduct small-scale clinical trials in situations where novel neurotechnological interventions might be invasive and involve some (possibly unquantifiable) risk.

- **The private sector has an important role in the development of responsible innovation practices in global markets**. Companies – and especially start-ups – are at the forefront of neurotechnology innovation. Responsible technology development and effective governance must involve the private sector as a central actor early on, especially in global contexts. At the same time, the private sector has a key interest in demonstrating responsibility and integrity.
- **An explicit commitment to principles of responsible development *upstream* can promote the trust and trustworthiness that are crucial for success.** Responsible design considerations early in the pipeline as part of the innovation process itself can support the social robustness and acceptability of new products and services, increase end-user trust, and ensure that innovation delivers for and with society. Transparency is critical to build trust in the ways data will be collected, managed and used. Experience with innovation trajectories in other emerging technologies (e.g. nanotechnology) reveal that upstream engagement can be crucial for identifying and mitigating public concerns early in the development process. Companies are keenly aware that the entire neurotechnology business sector can be harmed and public trust can be undermined by single bad corporate actors in the field.
- **Tools and approaches for responsible governance of neurotechnology are emerging.** There has been considerable experimentation among companies about how to address the unique social, ethical, and legal aspects raised by novel neurotechnology, especially those related to the collection and use of 'personal brain data'.[2] Emergent "good practices" in the private sector include for example the appointment of advisory boards on ethical, legal and social questions; the development of guidelines and principles; greater emphasis on responsible technology transfer; and interest in socially responsible investment. Importantly, many approaches known from the public sector do not easily translate to companies. Especially start-up companies lack the organizational and financial resources, and face considerable pressures of speed and scale that tend to discourage costly and slow deliberative exercises. Moreover, approaches from other sectors do not easily translate to neurotechnology. A mix of soft and hard governance tools (e.g. industry standards, regulatory processes) is needed for different sectors and different applications. These should provide clear pathways for developers that give certainty in routes to market as well as gaining societal approval. Experience with other emerging technologies suggests opportunities in including roles for researchers, clinicians, industry, governments, and civil society in governance models. Frameworks such as Corporate Social Responsibility could be enriched with approaches of Responsible Research and Innovation, and vice versa.

[2] 'Personal brain data' is information relating to the functioning or structure of the human brain of an identified or identifiable individual that includes unique information about their physiology, health, or mental states.

- **Sound regulation is key to enable robust innovation trajectories.** Soft-law measures and self-regulation are important building blocks of responsible innovation. However, clear and better aligned regulatory frameworks are equally needed to create certainty and ensure a high-level of user protection. Overall a functional, bottom-up approach, starting with the assessment of the technical peculiarities of different classes of applications, is to be preferred to the adoption of broad and all-encompassing principles. Simplification of extant solutions – in particular in fields such as civil liability – ought to be pursued, also by replacing existing strategies with a risk-management approach. Standardisation and product safety regulation is also essential to grant users' protection and clear compliance criteria developers need to abide by. Ethical guidelines, even when reflecting differences in culture, traditions and sensitivities, not to be intended as a replacement for regulation, contribute to the development of a responsible research and innovation approach.
- **Standards are critical.** Standards for neurotechnology innovation can help ensure a positive impact on health and society. Harmonized terminology, processes and standards not only enable investment in brain science and neurotechnology development, they also form the basis for impartiality, equal treatment, confidentiality, ethics, scientific integrity and transparency. International efforts on the standardisation of neurotechnology system specification and interoperability would help communication and collaboration across major brain research initiatives and the private sector.
- **There are large potential gains to be derived from data sharing**. International collaboration in neurotechnology innovation should include a focus on sharing of personal brain data. Significant cultural differences exist, and a diversity of governance systems can complicate data sharing. The standardisation of personal brain data collection, curation, and sharing will not only drive new discovery, but will also be essential to obtain broader value from the data. Intellectual property consists not in the data itself, but in what discoveries can emerge from its analysis. Privacy concerns will always have to be taken into account.
- **Public deliberation can contribute directly to value creation**. Public engagement is critical in the development of robust neurotechnology futures and for a comprehensive governance approach. Innovation in neurotechnology must be a collaboration between science and society: currently, the public is frequently viewed through the lenses of knowledge deficits and trust deficits. There is a need for a broader discussion to help define goals and elaborate scientific questions. Such a discussion is critical for developing trust and trustworthiness with end users, and can help tailor emerging technologies better to the needs of those they are designed to help.
- **Investors play a key role in enabling responsible innovation**. Investment is the lifeblood of the start-up driven neurotechnology industry, without which innovations cannot reach the marketplace. Questions of funding, public-private partnerships, grants, and public markets play a key role for addressing challenges of responsible innovation effectively. Guidance on "responsible investment" could help support such efforts.
- **There would be utility in developing a set of international Principles**. 'Principles for Responsible Innovation in Neurotechnology', such as those being

developed by the OECD Biotechnology, Nanotechnology, and Converging Technologies Working Party (BNCT), could complement, inform, and harmonize international guidance and norms. These Principles could support responsible innovation in neurotechnology, help governments better assess the ethical, legal and social issues (ELSI) of these technologies, and elicit policy responses that maximize benefits while minimizing risks. They should not generalize across the entire spectrum of neurotechnology and should be aimed at all actors in the innovation process. Any movement towards Principles should recognize the diversity of ethical values across countries and make acceptable accommodations, yet identify common ground on which norms, standards and regulatory provision can stand.

1. Introduction

Emerging neurotechnologies, defined as "devices and procedures that are used to access, monitor, investigate, assess, manipulate, and emulate the structure and function of neural systems" (Giordano, 2012[1]; OECD, 2017[2]), have the potential to radically change how to understand human cognition and behaviour. They also offer tremendous potential for the promotion of health, well-being, and innovation-driven economic growth. Non-invasive wearable devices using EEG-monitoring of cortical zones can help map and train brain activity and steer machines through brain-computer interfaces controlled by users and could be especially important for use by individuals with a motor-disability. They can also provide real-time feedback on current cognitive patterns and can be used to induce transcranial stimulations to manipulate brain activity.

Neurotechnology is also increasingly becoming a data science, redefining what is possible in terms of monitoring and intervention in clinical and non-clinical settings, with great promise for improving mental health, well-being and productivity. Here, the convergence between neuroscience, engineering, digitalisation, and AI is a key driver of innovation and will disrupt existing practices as well as traditional boundaries between medical therapies and consumer markets. For example, digital phenotyping technology as developed by the company Mindstrong Health and others can help anticipate emerging mental health problems through pattern recognition in cell phone usage, and launch targeted interventions. AI-driven clinical software support tools, such as Predictix (an AI-driven approach to personalize medicine, Taliaz, Israel) or Aifred Health (machine learning techniques predict treatment efficacy, Aifred Health, Canada), can be used to personalize antidepressant medication and improve mental health treatments.

These developments are not neutral, but foreseeably have an impact on societies, for example on how to judge and manage human health and behaviour, and which forms of medical interventions to consider legitimate. Neurotechnology therefore holds tremendous opportunities to improve health and well-being through innovation, but also raises questions about its responsible governance and use. These questions concern for example the possibility of human enhancement, changing personality, and intervening in self-perception. Also, issues around unauthorized use and misuse of personal brain data have become more tangible in the wake of recent privacy breaches in the social networking community. Other governance issues are raised when products intended for clinical use are used in non-therapeutic settings. In many of these questions, neurotechnology is unique in part because of the close connection of the brain and cognition to human identity and agency (Nuffield Council on Bioethics, 2013[3]).

Ethical, legal and social issues (ELSI) surrounding neurotechnology affect the entire innovation pipeline, from fundamental brain research, cognitive neuroscience, and other brain-inspired sciences (Jeong et al., 2019[4]; Greely, Ramos and Grady, 2016[5]; Salles et al., 2019[6]) to questions of commercialization and marketing (e.g. direct-to-consumer marketing of wearable, non-invasive applications based on claims about improvement of cognitive performance and well-being) (Eaton and Illes, 2007[7]; Martinez-Martin and Kreitmair, 2018[8]; Wexler, 2016[9]). The translation of neurotechnology into medical settings raises yet another set of issues, e.g. around the protection of health data acquired through neurodiagnostic devices, or the trust in medical assessment tools based on machine learning pose (Finlayson, Bowers and Ito, 2019[10]).

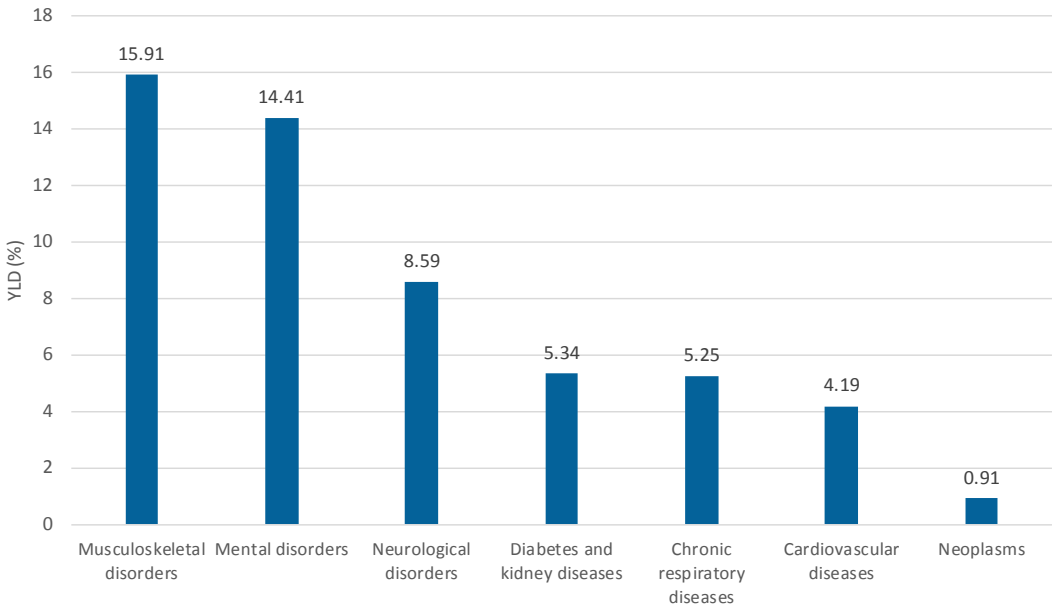
The private sector is a major driver of neurotechnology innovation, benefitting from large-scale national or international brain research and technology initiatives. Companies and investors hence play a key role for ensuring the responsible development and governance of emerging technologies, alongside public sector research actors such universities and governments. Yet, tackling questions of responsible innovation at the interface between public and private sector interests raises a number of challenges, as revealed by the OECD Shanghai Workshop. Companies face very different constraints and environments for research and development than public institutions, including an imperative of speed, scale, and profitability. Data collection and sharing raise additional issues for many products and services. Companies are facing heterogeneous and potentially rapidly changing regulatory landscapes across countries and regions. Yet another challenge is how to mobilize investment such as to enable the responsible translation of cutting edge neuroscience into markets with a view beyond purely financial returns toward the public good.

Novel anticipatory frameworks and good practices for the responsible governance of novel neurotechnology are beginning to emerge, both from the private and the public sector. In the private sector in particular, this includes for example the appointment of advisory boards on ethical, legal and social questions; the development of internal guidelines and principles; greater emphasis on responsible technology transfer; and interest in socially responsible investment. Principles for Responsible Innovation in Neurotechnology, as currently under development by the OECD, could provide a reference for governments and innovators for the responsible translation of brain research into products and markets.

2. A public health priority and a market opportunity

Mental health is an increasingly important public health concern in OECD countries and beyond. Mental and neurological disorders cause great human suffering and increasingly recognized as major causes of death and disability worldwide (Feigin et al., 2019[11]; James et al., 2018[12]; Vos et al., 2016[13]) (see Figure 1). They often remain untreated and impose significant economic and social welfare costs, elevating their importance to the highest national and international policy levels. In Europe, mental illnesses (e.g. depression, anxiety disorders and alcohol and other drug use disorders) alone affect more than one in six people with an estimated total cost of over EUR 600 billion in 2015 (OECD/EU, 2018[14]). The direct and indirect costs of mental health problems are significant, and can amount to over 4% of GDP (Hewlett and Moran, 2014[15]). A report by the World Economic Forum and the Harvard School of Public Health (2011[16]) estimated the global economic costs of mental health conditions in 2030 at USD 6 trillion.

Figure 1. Years Lived with Disability (YLD, %) for some non-communicable diseases



Note: To estimate Years Lived with Disability (years of life lived with any short-term or long-term health loss, YLD) for a particular cause in a particular time period, the number of incident cases in that period is multiplied by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). Incidence: the number of new cases of a given disease during a given period in a specified population. Neurological disorders are diseases of the central and peripheral nervous system (e.g. epilepsy, Alzheimer's disease and other dementias, cerebrovascular diseases including stroke, migraine and other headache disorders, multiple sclerosis, Parkinson's disease, neuroinfections) (http://www.who.int/features/qa/55/en/). Mental disorders comprise a broad range of problems generally characterized by some combination of abnormal thoughts, emotions, behaviour and relationships with others (e.g. schizophrenia, depression, intellectual disabilities and disorders due to drug abuse) (http://www.who.int/mental_health/management/en/).

Source: Institute for Health Metrics and Evaluation (IHME), USA (http://ghdx.healthdata.org/; http://ghdx.healthdata.org/gbd-results-tool), accessed 25 April 2019. Year: 2017. List of countries: http://ghdx.healthdata.org/countries. The Institute for Health Metrics and Evaluation (IHME) is an independent global health research center at the University of Washington (USA). The Global Health Data Exchange (GHDx) is a data catalog created and supported by IHME.

As a public policy topic, mental health is strongly related to global demographic trends, especially ageing populations in developed countries (United Nations, 2017[17]; World Health Organization, 2013[18]). By 2050, the world population will likely grow to 9.8 billion people, with one in five aged 60 years or older (United Nations, 2017[17]). In Japan, the proportion of people older than 60 years already exceeds 30%. Many other countries in North America, the EU, but also Chile, and South Korea, and Australia face similar issues of demographic ageing (World Health Organization, 2015[19]).

Dementia is one of the main targets of mental health initiatives and research world-wide. Dementia is a general term for progressive (usually age-related) decline in brain functionality affecting memory, thinking, behaviour and emotion. Dementia affects 50 million people worldwide with an estimated worldwide cost in 2018 of USD 1 trillion (including costs for informal care) (Alzheimer's Disease International (ADI), 2018[20]). By 2050, it is estimated that 152 million people will be living with dementia (Alzheimer's Disease International (Alzheimer's Disease International (ADI), 2018[20]). Currently there is no cure for dementia and no effective treatment that can stop disease progression. Despite remarkable discoveries in dementia research, drug development in Alzheimer's disease and other dementias has been marked by disappointments (Hodges, 2015[21]; Larson, 2018[22]). Systems theory, precision pharmacology und medicine (Hampel et al., 2017[23]; Hampel et al., 2019[24]), the convergence of engineering science and artificial intelligence (Ding et al., 2019[25]), and the development of novel health technologies (OECD, 2017[26]) offer powerful tools to better understand human brains and to close the treatment gap in Alzheimer's disease and other dementias. As part of the EU Human Brain Project (HBP) scientists are developing real-time simulation of large biological neural networks to mimic the brain's neural networks with the aim to better understand neural processing in the brain and shed light on the pathological processes leading to disorders such as epilepsy and Alzheimer's disease (van Albada et al., 2018[27]).

Dementia and other mental health diseases are one major driver of current neuroscientific research and technology development, both in the public and the private sector. Studies suggest that a cognitive reserve (cognitive resilience) can help tolerate more neurodegeneration with less functional decline and psychiatric symptoms (Arenaza-Urquijo, Wirth and Chételat, 2015[28]; Livingston et al., 2017[29]). It could be argued that factors that are potentially influencing cognitive reserve, such as genetics and epigenetics, education, social inclusion, and mental and physical stimulation, open up new avenues for diagnosis, prevention, and therapy in Alzheimer's disease and other dementias (Russ, 2018[30]; Weiler et al., 2018[31]). For example, AI-supported analysis of digital data from smart phones could offer surrogates for laboratory-based neuropsychological assessment (Dagum, 2018[32]), and initial studies indicate potential efficacy of deep brain stimulation (DBS) in Parkinson disease (Hickey and Stacy, 2016[33]; Limousin and Foltynie, 2019[34]). However, the use of computerized cognitive training as an option for maintaining cognitive function in normal aging has shown inconclusive results (Gates et al., 2019[35]).

Yet, neurotechnology comprizes a much more expansive set of research and economic activities. The growing interest in neurotechnology is linked to key industries such as healthcare, education, information and communication technology, and law enforcement. Beyond clinical applications, neurotechnology also has significant potential for the

development of direct-to-consumer (DTC) products and services, for example around the self-monitoring of cognitive health and well-being, optimizing cognitive performance, education, and communication technology (Ienca, Haselager and Emanuel, 2018[36]).

Table 1. Key patent filing locations.

Numbers of new patents filed 2008-2016 for health-related neurotechnology.

Priority country	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
United States	1067	1092	994	1134	1113	1354	970	943	851	9518
China	101	82	166	211	310	363	481	779	943	3436
Korea	57	56	65	72	89	93	141	119	131	823
Japan	57	75	67	68	49	76	78	84	49	603
Patent Co-operation Treaty	24	20	47	64	46	68	61	64	53	447
Russia	18	27	26	26	30	27	26	49	76	305
Germany	45	35	53	49	44	33	58	43	38	398
European Patent Office	33	24	26	20	49	42	33	54	43	324
United Kingdom	25	11	13	15	20	29	28	35	45	221
Australia	48	34	6	31	12	20	12	19	16	198

Note: This Table shows the numbers of patents filed 2008-2016 within the area of health-related neurotechnology for each of the top 10 priority filing locations (United States, People's Republic of China, Korea, Japan, Patent Co-operation Treaty[3], Russia, Germany, European Patent Office (EPO), United Kingdom, Australia). Priority filing location: the patent authority in which the first registration took place. Key search terms used for health-related neurotechnology: neuromodulation, neuroprosthetic, neurorehabilitation, neurosensing, brain-computer interface, neuroimaging, mental health, mental disorders, neurological disorders, diagnostics, therapeutics, health monitoring, prevention.
Source: The primary data source for this analysis was the Derwent World Patents Index™, as accessed via the Derwent Innovation™ platform - both produced by Clarivate Analytics (June 2019).

Table 2. Key source of innovation countries.

Numbers of patents filed for key source of innovation countries based on inventor activity filed 2008-2016 for health-related neurotechnology.

Source of innovation country	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
United States	921	917	844	896	872	1102	795	753	675	7775
China	109	72	117	207	325	377	479	778	760	3224
Korea	15	13	23	18	60	95	142	117	129	612
Germany	53	55	52	82	61	57	72	69	54	555
Australia	63	41	22	76	53	53	50	51	54	463
Israel	27	47	26	58	55	47	34	51	30	375
Canada	25	19	34	16	34	57	34	31	29	279
Switzerland	29	25	45	25	24	39	40	31	28	286
Japan	11	32	24	33	22	40	34	38	28	262
France	11	17	17	21	16	30	53	43	31	239

Note: This Table shows the number of patents filed 2008-2016 within the area of health-related neurotechnology for each of the key source of innovation countries (United States, People's Republic of China, Korea, Germany, Australia, Israel, Canada, Switzerland, Japan, France). Source of innovation countries: address of inventor filing a patent. Key search terms used for health-related neurotechnology: neuromodulation, neuroprosthetic, neurorehabilitation, neurosensing, brain-computer interface, neuroimaging, mental health, mental disorders, neurological disorders, diagnostics, therapeutics, health monitoring, prevention.

[3] https://www.wipo.int/pct/en/texts/articles/atoc.html

Source: The primary data source for this analysis was the Derwent World Patents Index™, as accessed via the Derwent Innovation™ platform - both produced by Clarivate Analytics (June 2019).

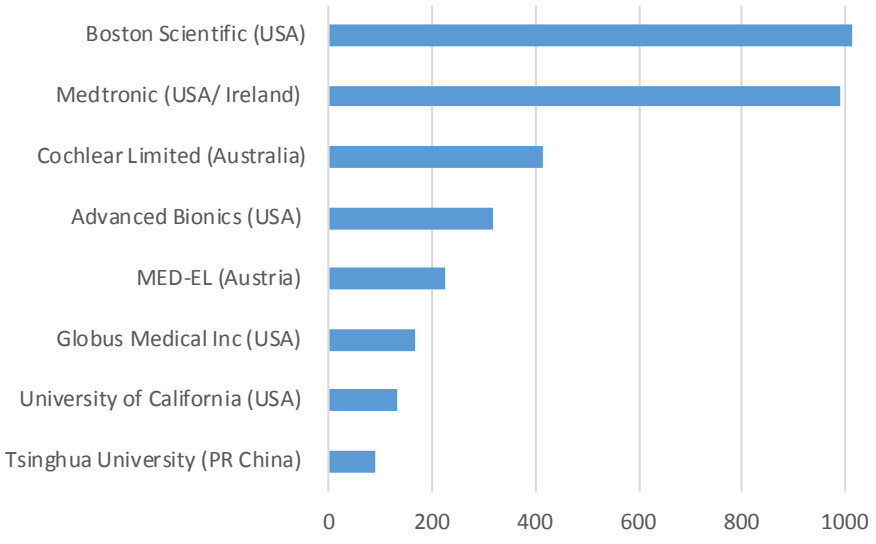
Worldwide a total of 16 273 patents in health-related neurotechnology have been field at key filing locations from 2008-2016 (see Table 1). In most countries the filings show an increased patent activity over the years, with the USA (9 518), People's Republic of China (3 436), Korea (823), and Japan (603) as leading markets. Complementary to the key filing locations, data shown in Table 2 provides information about the countries the a high innovation (research) activity in health-related neurotechnology: United States, People's Republic of China, Korea, Germany, Australia, Israel, Canada, Switzerland, Japan, France.

Medical device companies such as Boston Scientific (USA) followed by Medtronic (USA/ Ireland), Cochlear Limited (Australia), and Advanced Bionics (USA) are some of the top patents applicants by invention volume indicating dynamic activity of these assignees in the field of health-related neurotechnology. Academic institution, such as the University of California (USA) and the Tsinghua University (People's Republic of China) are noted among the top entities in this area (see Figure 2).

Among health-related neurotechnology, the following technological categories show high patent activity (total patent filings, 2008-2016): neuromodulation (10 375), neuroprosthetic (7 432), neuroimaging (1 854), neurosensing (1 768), neurorehabilitation (1 094), brain-computer interface (574), see Figure 3. The relatively high patent activity for neuromodulation technologies confirms this category as an important area of innovation.

Figure 2. Numbers of patents field by key applicants.

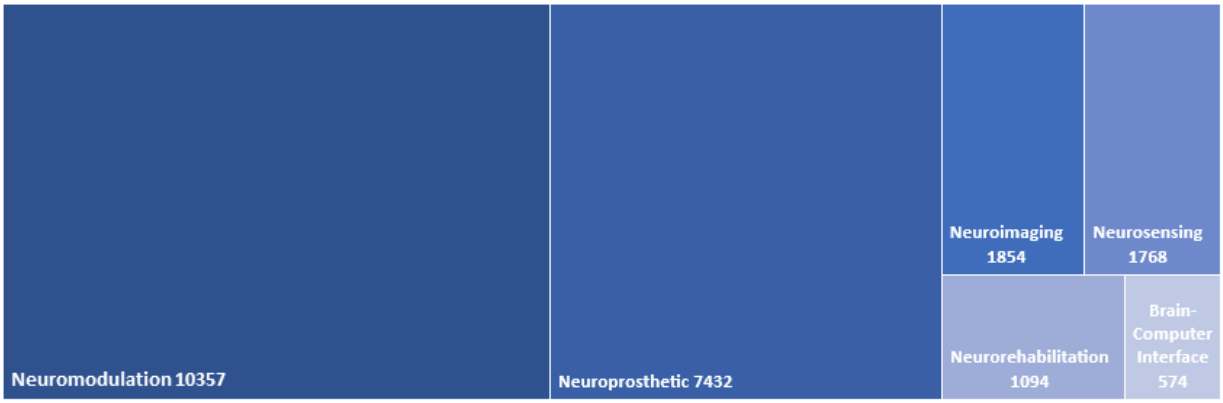
Total numbers of patents filed 2008-2016 for health-related neurotechnology.



Note: This Figure provides an analysis of the total number of patents filed 2008-2016 within the area of health-related neurotechnology for each of the top 10 priority filing locations (United States, People's Republic of China, Korea, Japan, Patent Co-operation Treaty, Russia, Germany, European Patent Office (EPO), United Kingdom, Australia). Priority filing location: the patent authority in which the first registration took place. Key search terms used for health-related neurotechnology: neuromodulation, neuroprosthetic, neurorehabilitation, neurosensing, brain-computer interface, neuroimaging, mental health, mental disorders, neurological disorders, diagnostics, therapeutics, health monitoring, prevention.
Source: The primary data source for this analysis was the Derwent World Patents Index™, as accessed via the Derwent Innovation™ platform - both produced by Clarivate Analytics (June 2019).

Figure 3. Patent activity for selected types of health-related neurotechnology

Total numbers of new patents filed 2008-2016 for selected types of health-related neurotechnology.



Note: This Figure shows the total numbers of new patents filed of selected types of health-related neurotechnology filed 2008-2016 for each of the top 10 priority filing locations (United States, People's Republic of China, Korea, Japan, Patent Co-operation Treaty, Russia, Germany, European Patent Office (EPO), United Kingdom, Australia). Priority filing location: the patent authority in which the first registration took place. One invention can fall into more than one category. Each category's invention count is independent of other categories.
Source: The primary data source for this analysis was the Derwent World Patents Index™, as accessed via the Derwent Innovation™ platform - both produced by Clarivate Analytics (June 2019).

2.1. Enabling translational brain research

Over the past years, neuroscience has experienced a massive increase in research activity and funding through large-scale, national and trans-national brain research initiatives, such as the EU Human Brain Project (HBP), the Japanese Brain/MINDS project, the Korea Brain Initiative, the U.S. Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative®, and the emerging Australian Brain Initiative, and the China Brain Project. These initiatives aim to shed light on the biological basis of mental and neurological processes and disorders, and on how to define cognition, emotion and consciousness. They are also a major driver of technology development, both through new tools to understand the brain and through commercial applications arising from this understanding (OECD, 2017[2]).

Table 3. Issues and opportunities in neurotechnology translation

Issues in Neuroscience Translation	Possible Solutions
Inadequate access to cutting edge technology for clinical research in academic institutions.	Development of technology platforms which include public-private partnerships that both invest in early stage research and have the capacity to take discoveries to market.
Large neuroscience data sets require significant resources for the validation, management, storage, and analysis.	Standardisation of data should start already when the data is generated in order to optimize sharing and downstream use. Governments must support the infrastructure to manage and store valuable data in the longer term.
Complex and lengthy contract negotiations between public institutions and private entities in partnerships.	Guidance on how to simplify processes for research translation and collaboration with companies.
Stringent ownership of data and IP.	Sharing publically-funded neuroscience data in an open science environment and allowing IP on discoveries that develop novel ways to use the data.
Ethical, legal, and social issues for translation and technology use.	Development of guidelines and principles analysing how novel technologies impact individuals and society. Implementation of frameworks of responsible innovation upstream.
Unrealistic expectations by users of neurotechnology and the broader public diminishes trust.	Avoiding hype and provide evidence-based information for experts and the publics. Stakeholder engagement and communication between research participants, patients, members of the public.

Source: OECD Shanghai Workshop, September 2018.

Translational brain research – the application of novel neuroscientific or biological knowledge and clinical trials of novel techniques and therapies that address critical medical and health needs – is one goal of all of these flagship initiatives. Translational principles are reflected in project design in various ways. For example, governments use these initiatives to actively foster connectivity across diverse stakeholders – on a national level and globally – and disciplines in order to help the transfer of knowledge into novel neurotechnology. These flagship brain research and technology initiatives are large-scale, complex, and heterogeneous endeavours, reflecting an understanding that brain science and neurotechnology are platform technologies enabling broad applications to multiple products, processes, and markets. They emphasize collaboration, openness, and information sharing as important factors in realising opportunities and managing risks, especially in novel, often disruptive technologies.

Brain research initiatives are also important vehicles for governments to shape the neuroscience research agenda towards concrete policy goals in public health and social well-being. Some initiatives include explicit considerations of how to integrate elements of social responsibility and ethics into their technology transfer, business practices, research and development (R&D), and corporate governance. In order for those technologies to be integrated into society, they need to be developed together with society for markets and broadly disseminated beyond the laboratory or company where they originated. Closer collaboration between brain initiatives around the world will accelerate discovery and innovation. These international, public-private collaborations could offer a 'test bed' for new approaches to information sharing, intellectual property (IP) management, public engagement, and incentivising open science and responsible innovation. Possible roadblocks and solutions for the translation of research into products within brain initiatives are summarized in Table 3.

Translational ambitions go beyond the scope of individual initiatives. The International Brain Initiative (IBI) is a new global body that has formed to coordinate the activities of

the major brain initiatives around the globe.[4] The vision of the IBI is catalysing and advancing ethical neuroscience research through international collaboration and knowledge sharing, by uniting diverse ambitions to expand scientific possibility, and disseminating discoveries for the benefit of humanity. Working groups have been formed to coordinate global neuroethics, an inventory of projects across the initiatives, data sharing, tool and technology dissemination, education and training and communication and public outreach. The IBI seeks to engage with governments and policy makers and global organisations.

[4] http://www.internationalbraininitiative.org/

3. Ethical, legal and social challenges

The 2018 OECD Shanghai Workshop "Minding neurotechnology: delivering responsible innovation for health and well-being" showed that neurotechnology governance requires serious engagement with the private sector to ensure responsible development in this domain. Emerging neurotechnology products and services in neuroimaging, brain-computer-interfaces, and neurostimulation are raising questions by companies and consumers alike, for example on the privacy of personal brain data, the reliability and validity of automated cognitive assessment, and potential off-label and misuses of neurotechnologies (Bowman et al., 2018[37]; Garden and Winickoff, 2018[38]; Kaebnick and Gusmano, 2018[39]; Nuffield Council on Bioethics, 2013[3]; Müller and Rotter, 2017[40]). The meeting also demonstrated that private sector actors are keenly aware of the need to bring innovation processes into alignment with societal needs, values and expectations in order to reap the full potential of their innovations.

The ethical, legal and social challenges surrounding these emerging technologies affect the entire innovation pipeline, from fundamental brain science (e.g. acquiring informed consent) to questions of commercialization and marketing (e.g. direct-to-consumer marketing of wearable, non-invasive applications based on claims about improvement of cognitive performance and well-being) (Eaton and Illes, 2007[7]; Martinez-Martin and Kreitmair, 2018[8]; Wexler, 2016[9]). The translation of neurotechnology into medical settings raises yet another set of issues, e.g. around the protection of health data acquired through neurodiagnostic devices, or the trust in medical assessment tools based on machine learning pose (Finlayson, Bowers and Ito, 2019[10]).

The potential effects might be both more subtle and more transformative than anticipated in crude visions of 'mind control.' For example, if benign forms of cognitive training or neuro-stimulation enhance educational or other performance outcomes, they might create implicit expectations by employers and society at large, and putting at a disadvantage those who cannot afford them. Neurological information could also be reflected in insurance rates, creating new strata of vulnerable populations.

Additional consequential effects might unfold at the interface between neuro and data science. With respect to democracy and political participation, recent scandals such as those involving political analytics company Cambridge Analytica and Facebook have revealed the vulnerability of our political systems to concerted efforts of behavioural data gathering and targeted manipulation of social media. Likewise, targeted advertising based on digital phenotyping fuelled by big data and machine learning could, for example, enable retailers to increase sales, including of unhealthy products such as cigarettes, alcohol, and high-calorie foods, to those most susceptible to them (e.g. with a propensity towards alcoholism or addictive behaviour). This kind of manipulation of purchasing and consumption patterns can have direct and significant impacts on public health and on the costs of maintaining public welfare systems.

Other issues in the responsible development and use of neurotechnology include:

- **Digital footprint**: the adoption of neurotechnology and other personal health technologies in academia, clinical applications, and consumer markets, and recent privacy and security breaches in the social networking community have raised ethical, legal, and social questions about peoples' digital footprint, data ownership, storage, sharing, and validation (Greenberg, 2018[41]; Hernandez, 2018[42]). Ienca et

al. (2018[36]) argued that "creating an ecosystem that enables technological innovation while making sure that citizens have control over their data is critical for neurotechnology".

- **Manipulation**: neuroimaging and brain stimulation technologies are being used with growing potential in research and increasingly in the clinics. Also, there is significant potential in courts for testing the veracity of testimony and for marketing purposes (Smith, 2013[43]). Decoding brain activity, thoughts, and mental states bears the risk of unauthorized monitoring, judgement, manipulation, and discrimination (Poldrack, 2017[44]; Racine and Affleck, 2016[45]; Robillard and Illes, 2016[46]). It should be noted, however, that validating systems and providing the evidence about the 'truth of people's thoughts' in real world settings remains a major challenge. Given that personal brain data are privacy-sensitive data types that can potentially reveal predictive information about health status, mental states and behaviour, and that the manipulation of brain activity via brain stimulation can influence personal identity, neurotechnology raises important implications also from the perspective of human rights (Cabrera, Evans and Hamilton, 2014[47]; Ienca and Andorno, 2017[48]).
- **Transparency**: emerging technologies are not neutral and can impact and fundamentally alter society. Drawing on work on AI, a "Meticulous Transparency" assessment has been developed by Benrimoh et al. (2018[49]). This framework also requires developers to provide details on intentionality, scope of use, data sources and bias control, human interpretability, the projected risks and benefits of the product, monitoring and contingency plans for adverse events.
- **Technology misuse**: the complexity and disruptive potential of recent advances in neurotechnology have raised public concerns about their potential misuse (Bowman and Husbands, 2011[50]). Examples of neurotechnology misuse include the unsafe use of do-it-yourself (DIY) technology for cognitive enhancement, malicious 'neuro-hacking', and neuro-doping are some examples of potential technology misuse that require discussion by all stakeholders (Aicardi et al., 2018[51]; Park, 2017[52]; Wexler, 2017[53]).

Will cognitive enhancement technologies be designed to maximize certain behaviours that favour the interests of the most power players? Will commercial EEG or other self-monitoring technologies be used to fuel a new "bio-advertising" market, where personal biological measures are used to target products to people in more and more irresistible ways? Will personal brain data exacerbate current tendencies of irresponsible and non-transparent data collection and monopolization? These are the questions that drive current discussions around regulatory scrutiny and responsible business development in neurotechnology.

The potential of neurotechnologies to influence human behaviour in ways that society may not be aware of should not be taken lightly, especially given that many of these technologies are being developed with behaviour alteration as an explicit goal (i.e. those technologies that are therapeutics for mental illness). This does not detract from their enormous potential to benefit human health and well-being, but highlights the need for caution in the use of technologies that exploit biases and motivations that can influence human thinking and decision making. It will also be important to ensure that these technologies are democratized, so that neurotechnologies and AI are not solely tools to be used by and to benefit those who can afford their development.

Box 1. Opportunities and risks in human-computer interface technology

The development of human–computer interfaces and other cognitive technologies affects innovation and productivity through many routes, for example, increasingly intelligent and autonomous machines and systems, simulation-driven approaches to pre-clinical testing of potential therapies, and predictive analytics of health data in personalized medicine (OECD, 2017[26]). Human-computer interfaces draw on, for example, neuroscience, software engineering, sensing technologies, neuromorphic engineering (Bainbridge and Roco, 2016[54]).

The digital transformation of industries and the health sector will further strengthen the ties between human, machines, and algorithms. Enterprises increasingly rely on a mix of digital technologies and automated systems for their productivity. In the clinical sphere brain–computer interfaces (BCIs) offer important solutions to public health needs and for patients in neuronal rehabilitation (Abdulkader, Atia and Mostafa, 2015[55]; Wolpaw and Winter Wolpaw, 2012[56]). In addition, BCIs can be used to implicitly communicate information to a machine, allowing for neuroadaptive technology (Zander et al., 2016[57]). In that way, the interaction between human operators and machines becomes more natural and intuitive and the work gets more productive (Zander and Kothe, 2011[58]).

Although techniques for human-computer interactions have become increasingly user-friendly they still depend on a computer as an operator to translate their original thought or intention into a sequence of small, explicit commands, which presents both a communication bottleneck and a source of potential error. New approaches to human-computer interfaces, that preserves the resources of the human operator while enabling them to use the full potential of the machine hold a potential to widen this bottleneck and minimize the risk of failure.

Even though significant advances have been made in this area by utilizing machine learning for smart automation, risks and consequences of system fragility may increase and the ability to anticipate system failures could diminish (Leveson, 2011[59]). Here, the merger between human oversight and artificial intelligence (AI) in human-computer interfaces could further promote a human-centric approach and increase the robustness of systems through simultaneous and continuous learning (OECD/EU, 2018[14]; OECD, 2019[60]). In this vein, Specker Sullivan and Illes (2018[61]) note that ethics capacities and reporting in BCI research can be improved through (1) the explicit reflection on the value, goals, and methods in human subjects study design, and (2) openness and transparency about ethics practices in reporting.

4. Role of the private sector in neurotechnology governance

Both internal and external drivers have brought the issue of responsibility to the forefront in neurotechnology businesses. Internally, some companies are already leading by example by including social responsibility into their core vision of technology development and establishing their own mechanisms. Interactions between researchers, companies, regulators, and user and patient communities have been quite strong, including through the activities of government agencies such as the U.S. National Institutes of Health (NIH). A very active academic community around neuroethics and science & technology studies (STS) community has been part of many developments. Externally, neuroscience and neurotechnology have received growing international attention internationally, most notably through large-scale flagship research initiatives such as the EU Human Brain Project (HBP) and the U.S. BRAIN initiative. Conversely, recent public controversies around human enhancement and a broader wave of technology 'backlash' raised the stakes for the prospects of this nascent sector. This has sparked an increase in further collaborations among companies and social scientists in the domain of AI ethics and the new field of 'Public Interest Technology'.

There is currently a window of opportunity to address ethical, legal, and social issues. Neurotechnology is a relatively young field where many promising applications are still in research and trial phases. "Upstream" engagement can help avoid costly design lock-ins and reduce the need for costly adjustments at a later stage to ensure market compatibility of emerging products and services (see Figure 6). What is more, there is a growing awareness and sensitivity of these issues in the neuroscience-community. International flagship projects such as the US BRAIN Initiative and the HBP are embracing the growing interactions with neuroethicists and policy makers, which is representative of a general desire among stakeholders to address potential issues of future applications early on.

4.1. Key opportunities, risks, and barriers

The OECD Shanghai Workshop underscored the potential opportunities arising for companies from engaging with questions of responsibility. Neurotechnology companies recognize that they can develop a competitive advantage by building a reputation as responsible technology leader and demonstrating integrity. An explicit commitment to principles of responsible development of neurotechnologies "upstream" – i.e. responsible design considerations early in the pipeline as part of the innovation process itself – can boost the social robustness and acceptability of new products and services, increase consumer trust, and ensure that innovation 'really matters to society' (Wilsdon and Willis, 2004[62]). Experience with innovation trajectories in other sectors (e.g. biotechnology or digital platforms) reveal that upstream engagement can be crucial for identifying and mitigating public concerns early in the development process (Nuffield Council on Bioethics, 2012[63]). Moreover, there is growing evidence that integrating a plurality of perspectives upstream in the design of innovations will improve technology design, enable new creative solutions, and facilitate trustworthy governance (Sutcliffe, 2011[64]).

Nevertheless, there are perceived risks associated with introducing responsibility mechanisms into the innovation processes indiscriminately. Processes of public deliberation and anticipatory governance, widely used in the public sector, tend to be time and resource intensive, and hence can slow down R&D processes or stifle innovation.

Moreover, some companies consider attention to responsibility outside their core mission of revolutionizing healthcare, education, or consumer entertainment, and second to the imperative of delivering shareholder value. Workshop participants thus emphasized that responsibility tools must be carefully tailored to the needs and constraints of the private sector. At the same time, participants recognized the risks in not addressing questions of responsibility head-on. A lack of public debate and international standards might lead to a race to the bottom in terms of regulatory control, or may encourage rogue behaviour that can evaporate trust in an entire field through a single "kill event." A central challenge is how best to mobilize societal and regulatory engagement without stifling innovation is a central challenge.

A number of barriers currently prevent stakeholders to effectively address questions of responsibility in and with the private sector. First, established pathways for responsible innovation in public sector research – such as deliberative exercises or ethics boards – do not easily translate into the private sector. Second, the unique questions and societal implications of emerging neurotechnologies (such as concerns with human agency, brain privacy, or behavioural control) make it unlikely that tools and approaches mobile

zed in other technology domains will be directly applicable or effective. Third, many young, innovative companies – and especially start-ups – tend to lack time and resources to commit the necessary organizational capital. Instead, they are primarily bound by demands for scale and returns by investors, which skews incentive structures. Finally, there is a lack of awareness of some of the issues in the public so that less public debate is happening than would be helpful.

A number of leading neurotechnology companies share a commitment to certain core values that should guide research and development. These values include maximizing social impact and health benefits; prioritizing safety and efficacy; committing to integrity, honesty, and trustworthiness; emphasizing transparency and privacy protection; enabling responsiveness to social concerns; and being consistent with stated goal and action (see Figure 6). Companies recognize that competitive pressures and vested interests may limit the extent of self-governance that can be expected from the private sector, which provides a rationale for public-private engagement to develop adequate policies and oversight.

One-size-fits-all solutions for responsibility challenges are not possible: regulatory approaches will have to be both context and application specific. The particular approach taken will depend on the area of application, e.g. whether a technology is intended for scientific research, medical use (prevention, diagnosis, therapy), or non-medical use (well-being) as well as the envisioned user (e.g. a medical practitioner, a commercial end user, a company). It also depends on the technology readiness level and the perceived level or risk. Societal response and corresponding approach depend on the specific social, ethical, demographic, cultural, and legal environments. Finally, the unique questions and societal implications raised by novel neurotechnology (such as concerns with human agency, brain privacy, or behavioural control) make it unlikely that tools and approaches mobilized in other technology domains will be directly applicable or effective.

Figure 4. Implementing social responsibility into neurotechnology companies

Source: OECD Shanghai Workshop, September 2018.

4.2. The unique position of start-ups

Companies, especially innovative start-ups, face a very specific set of challenges to engage with questions of social responsibility in their daily routines, as the workshop underscored. These challenges include an imperative of speed and scale, dependence on investors for company strategy, a lack of dedicated organizational capabilities to deal with responsibility in R&D, and unclear regulatory contexts across countries. Business models that explicitly take into account questions of social responsibility all the way from research to marketing are still evolving.

Established pathways for responsible innovation in public sector research, such as deliberative exercises or ethics boards, operate on very different timescales or are not easily brought into corporate R&D processes. Moreover, accountability structures differ. However, many of the main goals for Responsible Innovation are identical for the public and private sector: anticipating potential regulatory issues ahead of time, ensuring that research is conducted inclusively such as to benefit from diverse inputs and potential uses, and demonstrate the legitimacy and social licence of ongoing research and development activities.

While practices and tools for responsible innovation for established companies are still emerging, even less is known about how start-ups and or teams at pre-commercial incubation stages can adopt and implement socially responsible innovation methods and business conduct. Yet, this start-up phase might be even more important for current development in neurotechnology than a focus on larger firms. Start-ups are becoming some of the most exciting venues for breakthrough tools in basic and clinical neuroscience, from visualizing neuronal activity in the mouse brain to digital phenotyping in the clinic. With this success, a new set of questions is emerging around ethical, legal, and social implications of neurotechnology in the start-up world. How will data be shared in companies that are protecting their intellectual property? This might include, for example, a question about whether experience of early clinical experimentation can be shared (e.g. through registries) in order to maximize research opportunities and to avoid repetition of trials with negative results. How is privacy protected for clinical technologies sweeping up vast amounts of individual neurological or behavioural data? How should governments regulate software-based tools that are adapting continually? Who is responsible for maintaining and updating technologies once they have been deployed, particularly in health settings? What are the social implications of technologies that can monitor cognition and behaviour? When does monitoring become surveillance?

The situation of start-ups poses a range of critical challenges for responsible innovation routines. Here, the imperative of speed and scale is ever more pronounced than for established firms, and the focus is primarily on creating a commercially viable product in the first place. Start-ups usually do not have the size, organizational resources, or financial means to tackle responsibility as a key issue. Moreover, investors play a key role in making strategic decisions for start-ups and will have to be active players in the development of responsible innovation mechanisms as well. Hype, unsubstantiated medical claims, and potential misinterpretation, and off-purpose use pose significant risks to innovators and investors alike. Neurotechnology start-ups at the Shanghai Workshop emphasized that the investor chosen by the company should be in line with the values and business strategy, especially from a perspective or responsibility.

Another challenge is the difference in environment between start-ups and university-based research. Start-up companies are often created by academic investigators who want to commercialize discoveries made in a university laboratory and who are used to the institutionalized ethics procedures in university settings. Yet, while the origin might be in a university, the start-up culture is fundamentally different from the academic culture. In a start-up the focus is on more rapid product development than on papers or robust procedures; the development teams include engineers, designers, and data scientists; timelines are often much shorter; and the culture encourages risk and failure.

There are at least three major challenges that start-ups face compared to academic labs when developing neurotechnologies:

- First, the start-up needs to be able to build a product that innovates, in the sense that it offers a user something better than existing technology. Creating value and addressing health needs should be at the heart of product development. This requires not only great engineering and design but an eye to "product-market fit", which is an industry term for understanding the problem that needs to be solved.
- Second, as with an academic lab, the start-up needs to raise funding to support research and development. This usually depends on venture funds which come with an expectation of a financial return on investment. This means that in addition to creating an innovative product, the start-up needs to have a business model for commercialization. Questions that are rarely asked in an academic lab, such as "Who will pay for this?" and "How big is the market for this?", are fundamental to raising funds in a start-up.
- Third, for clinical products, start-ups need to test their technologies in patients. In contrast to academic labs, few start-ups have access to clinics. For the development of clinical tools, start-ups need clinical partners who are willing to work with a commercial entity while not necessarily sharing in the equity of the company. Managing these public-private partnerships for research can become complicated in an environment where universities want intellectual property. Moreover, guidance will be needed on how to conduct small-scale clinical trials in situations where novel neurotechnological interventions might be invasive and involve some (possibly unquantifiable) risk.

From the standpoint of start-ups, where development can be rapid and iterative, a process that includes users, developers, and investors in establishing guidelines will be critical. It is not possible to foresee all the unintended consequences of novel technologies but stakeholders can establish some fundamental principles that will guide their development. Transparency, agency, and privacy protection are all essential elements for the ethical development of neurotechnologies. User-centred design can help to translate these elements into specific features of software and hardware, often referred to as "ethically aligned design" (see next section). And a focus on empowering patients and families can also guide how these features are deployed.

Engagement with consumers (e.g. patients, clinicians) and other stakeholders will also ensure that innovative technologies meet their needs, and are more likely to be used and be effective. A major failure to translate innovative technologies is that they do not provide end-users with the benefits they want, or are used in ways that were not anticipated by developers, potentially causing unanticipated harm. Most of all, for neurotechnologies to be successful they need to gain and retain public trust in order to obtain a 'social licence' to operate. Some big technology companies and social media platforms are currently experiencing a "techlash" as the public questions the motives and values of large tech companies. Start-ups avoid some of this scrutiny but they still have the challenge of ensuring public trust through ethical behaviour that is focused on empowering users.

5. Design standards and regulation

The development and appropriate use of emerging technologies is frequently supported by standards that ensure technological robustness, interoperability, and general compliance with well-defined criteria and standards for safety and effectiveness. Standards therefore represent an important instrument to tackle questions of ethics and social responsibility, and can make a positive impact on science, technology development, and commercialisation. Governance frameworks for neurotechnology innovation should take into consideration standards for, e.g. safety, efficacy, manufacturing, and the compliance with existing data protection, intellectual property and medical device regulations, as well as fundamental human rights. However, given the low level of maturity of some neurotechnologies, there can also be some reluctance to establish strict standards given the multiple unknowns.

The question thus arises on how standards can be responsibly developed without unnecessarily slowing down the deployment of technology-based solutions. The IEEE[5] sponsored working group of Neurotechnologies for Brain-Machine Interfacing, chaired by Ricardo Chavarriaga (Defitech Chair in Brain-Machine Interface, Center for Neuroprosthetics & Institute of Bioengineering, School of Engineering, Polytechnique Fédérale de Lausanne, Switzerland), has been working on identifying the current state and priorities for standardisation in this field. It has first highlighted the need to recognize that these technologies are based on the integration of multiple subsystems, often based on other emerging technologies including AI, the Internet of Things (IoT), intelligent robotics and augmented/ virtual reality.

Consequently there is a great heterogeneity in the level of standardisation on the elements that compose neurotechnologies. For instance, there is a rather high level of standardisation on the safety and biocompatibility of traditional sensing technologies and prosthetic devices. In contrast there are practically no standards related to the system specification, interoperability or benchmarking of the functional capabilities of these systems.

One of the clear priorities for standardisation concerns data management. The possibility of widespread data sharing is important to promote new discoveries that reflect global diversity and differences across populations. However, cultural differences exist, and a diversity of governance systems can complicate data sharing (OECD, 2013[65]; OECD, 2014[66]). Nonetheless, the multiple ongoing projects on platforms to manage large quantities of data are being developed independently by separate entities (i.e. national brain agencies), without clear efforts to ensure compatibility across them.

In addition, data collection brings another priority area which is the protection of the data and the privacy of individuals. Noteworthy, this concern goes beyond neural technologies and should be addressed consistently for all data-intensive (AI-powered) activities. In particular, as stated in the Article 25 of the EU General Data Protection Regulation (GDPR), manufacturers should ensure data protection by design and by default, meaning that both the hardware and the software have been designed from the foundations as

[5] https://www.ieee.org/

secure.[6] It is thus important that current initiatives on governance and standards for neurotechnologies are coherent with efforts on data-related emerging technologies.

Given the fact that neurotechnologies are constantly evolving, standards and regulation should be able to accommodate developments at different levels of technological maturity. Hence, instead of a monolithic set of rules, standardisation should be approached as a coherent set of widely agreed of rules ranging from community guidelines and field-specific good practices for technologies at early stage of development to industry established standards for more mature developments and products. Proper integration across different levels of standardisation can facilitate faster and safer development and technology transfer from research to industry. Consistently, different types of governance may apply to each stage of the development and deployment of neurotechnologies.

Importantly, a coherent approach should be taken to ensure prioritisation of the ethical aspects, safety, subject protection and respect of cultural differences. Principles of ethics-, privacy- and security-by design should be thoroughly applied from early stages of research and development. In the same way, it is also important to have coherent regulation between clinical and consumer-oriented neurotechnologies. The latter are expected to play an important role on reducing access costs and will increasingly be used in healthcare and wellness applications. It is thus important for consumer-oriented devices to comply with relevant standards in terms of safety, efficacy and interoperability with clinically-graded equipment.

Given the fast development of these emerging technologies and the unavoidable uncertainty of their deployment in society, it is important to allow that standardisation and governance mechanisms rapidly evolve alongside new development. One example of flexible mechanisms is the draft guidance document "Implanted Brain-Computer Interface (BCI) Devices for Patients with Paralysis or Amputation - Non-clinical Testing and Clinical Considerations" released by the US Food & Drug Administration (FDA) (2019[67]). It is a leapfrog guidance mechanism by which agencies and regulatory bodies can "share initial thoughts regarding emerging technologies that are likely to be of public health importance early in product development". They are thus non-binding but represent the current stance, allows for community feedback and recognizes that recommendations are likely to change as technology evolves and more information becomes available. International efforts on this type of flexible, evolving recommendations would certainly help aligning current efforts in the development of neural technologies and strongly promote standardisation on system specification and interoperability.

In considering standardisation and soft law approaches, regulation should not be feared, for it does not necessarily impair or delay innovation. Quite the contrary, when well designed – through an empirical and functional approach – it creates a clear framework that allows technological development and its economies to prosper (OECD, 2019[60]). This is the perspective the European Commission adopted in its Communication of April 25th 2018 on "Artificial Intelligence for Europe"[7].

[6] https://gdpr-info.eu/art-25-gdpr/

[7] (2018). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. Artificial Intelligence for Europe. Brussels, European Commission.

Indeed, absent specific intervention, uncertainty might reside with respect to a number of issues, such as who bears liability in case of a malfunctioning or accident involving the use of some application, in particular if intended to function in close cooperation with human beings. Different sets of rules could overlap, thence simplification would certainly benefit the system. To this end, a risk-management approach (Bertolini, 2016[68]) could be conceived – also contemplated by the European Parliament in its recommendations from 16 February 2017[8] – whereby the party is held liable that is best positioned to identify the risk and manage it – also through insurance – without requiring the demonstration of an exact causal nexus.

Standardization and ex ante product safety regulation then play a central role in ensuring both a high quality product design – thence users' protection –, and a clear legal framework for businesses, allowing them to identify the requirements they need to abide by. Efforts in perfecting such body of norms, as well as the development of internationally recognized technical standards should be welcomed.

Regulation necessarily occurs at national and regional level. Aiming at the adoption of a global legal framework is largely unrealistic, and not necessarily beneficial in such technical matters. Indeed, if technology regulation occurred at regional – not merely national – level, the development of competing systems could be beneficial, allowing for alternative approaches to be tested, without causing excessive fragmentation.

To summarize, standardisation and regulation should be consistent with the fact that it is impossible to solve all the uncertainties before these technologies are deployed to society. Therefore, there should be mechanisms to properly inform society about the risks and benefits they entail, as well as the possibility of unforeseen outcomes. Complementary, developers are responsible for monitoring the impact of these technologies and should be ready to anticipate and react accordingly in case of negative outcomes. Proactive and flexible mechanisms for standardisation and governance will play an important role in the safe, responsible deployment of solutions based on brain science and neurotechnology.

[8] (2017). European Parliament resolution of 16 February 2017 with recommendations to the Commission on Civil Law Rules on Robotics (2015/2103(INL)), European Parliament.

6. Opportunities in soft law

At the Shanghai Workshop, the topic of soft law was explicitly discussed with respect to neurotechnology. While regulation refers to a system of rules that identify permissible and impermissible activities with sanction or incentives to ensure compliance, soft law refers to policy instruments with moral or political force but without legal enforceability. Examples of soft law include private standards, general policies, guidelines, principles, codes of conduct, and forums for transnational dialogue. The various instruments of soft law might be well suited to the governance of emerging technologies where there is often a need to operate at the global scale and where a flexible approach might be appropriate given the uncertain trajectories.

6.1. Development of principles

OECD Principles for addressing pressing ethical, legal, societal, economic and cultural challenges would be beneficial to support responsible advancement of novel neurotechnology. These OECD Principles could help governments better assess the impacts of neurotechnology and develop policy responses for reaping and sharing their benefits.

One major challenge for developing international principles or guidelines for responsible innovation in neurotechnology is the diversity of the field, both in terms of technologies and scientific knowledge involved as well as different regulatory contexts. The development of neurotechnology can involve contributions from different sectors, such as neuroscience and data science, in which there are different practices, standards and governance and regulatory requirements. Moreover, scientific advances and the emergence of new applications can transfer rapidly into different jurisdictions and areas of application. Common standards that nevertheless recognize different regulatory and cultural practices can help secure more rapid and effective collaborations and transfer of technologies so that clearer pathways can be found towards global dissemination and diffusion. This will necessarily involve elements of responsible research (soft governance) at upstream stages of the innovation process, and an understanding of regulatory conditions in areas of application where there are more specific conditions attached to market entry (such as medical devices). Far from being a barrier to innovation and development, engagement with such governance processes, alongside public involvement at all stages, can help secure public acceptability and clearer and more predictable routes through the innovation pathway.

Soft law measures, such as the Ethics Guidelines for a trustworthy AI[9], or the OECD Recommendation of the Council on Artificial Intelligence (OECD, 2019[60]), may not, and are not intended to replace the need for a sound regulatory framework. Such instruments, broader and more general in their assumptions, scope and conclusions, may instead be useful to shape a culture of responsible research and innovation. Even in such a perspective, however, the development of alternative, and competing models, reflecting different

[9] Available at https://ec.europa.eu/digital-single-market/en/news/ethics-guidelines-trustworthy-ai, adopted by the High-Level Expert Group on AI, appointed by the European Commission.

cultures, traditions and sensitivities, might be welcomed. Such diversity could support the testing of different solutions and of identifying those to be preferred.

Principles and guidelines, even when reflecting differences in culture, traditions and sensitivities, should not to be intended as a replacement for regulation, but contribute to the development of a responsible research and innovation approach. The regulation of emerging technologies requires novel approaches, that need to be bottom-up and functional. Indeed, it is necessary to gain an exact understanding of the functioning of technologies, dividing them into classes according to their peculiarities, observe how they interact with already existing norms, identify the issues they give rise to, and the incentives extant rules provide to all players involved (Leenes et al., 2017[69]). The tendency towards indistinct exceptionalism should be contrasted with attentive empiricism, distinguishing reality from science-fiction and inflated expectations.

It is the responsibility of governance bodies to align neurotechnology with democratic principles such as individual freedom, equality of opportunity and citizen involvement in public deliberation. A roadmap for democratizing neurotechnology should align innovation in this domain with the principles of openness, transparency, avoidance of centralized control, inclusiveness, and user-centeredness. The complexity of neurotechnology requires adaptive and multi-level governance frameworks that promote and take into consideration (Ienca and Andorno, 2017[48]):

- Quality standards and guidelines for neurotechnology producers.
- The calibrated balancing between the freedom to innovate and the promotion of privacy and security.
- The inclusion of diverse actors and perspectives in public deliberation.
- The protection of fundamental human rights.

6.2. Ethics and governance frameworks for neurotechnology

Governance frameworks are necessary as a way to ensure standard reporting of the capabilities and potential consequences of neurotechnologies, allowing societies to more easily grapple with their implications and the appropriate responses. The right frameworks should enable innovation, though help steer it to desired goals. Key requirements for frameworks for the governance of neurotechnology are developing standards and acquiring sufficient knowledge about the efficacy of neurotechnology. Successful governance frameworks should promote further research on standards for safety and effectiveness of neurotechnology, and anticipate potential public health or individual risk. For instance, currently, the efficacy of several consumer neurotechnologies is not conclusive and their grounding on solid scientific research is often loose (Ienca, Haselager and Emanuel, 2018[36]; Wexler and Reiner, 2019[70]).

The development of relevant frameworks is underway. In fact there are some using frameworks already both at the research phase and design phase, and there are many models from other areas of emerging technology that carry excellent ideas for the private sector (Coalition for Responsible Use of Gene Editing in Agriculture, 2017[71]; Knoppers et al., 2014[72]; Marchant and Allenby, 2017[73]; OECD, 2019[60]).

Neurotechnology innovation represents a special case for ethics-based approaches, which have been widely used other life science and technology domains. Neuroethics has evolved over the past 15 years. The early emphasis of the field on the ethics of neuroscience and an

embedded neuroscience of the mind, is shifting today to impact, and the decisions and decision-making tools that end-users must embody in absorbing neurotechnology into their lives and into their societies.

To this end, six critical concepts underlie responsible innovation on the part of the neurotechnology sector:

1. Neurotechnological exceptionalism, and the key role of neuroethics in guiding AIMs ([A]anticipate and articulate, [I] implement and integrate, and [M] monitor and measure) – recognising the need for caution, anticipating ethical targets, integrating ethical benchmarks, and monitoring and measuring outcomes.
2. Scientific, procedural, and ethical reproducibility, that ensures all aspects of reproducible study designs from the first elements of conceptualization to the furthest reaches of knowledge dissemination and exchange.
3. Given that there are varying cultural ecosystems, it is important to recognize that balanced (rather than universal) principles will help support the definition and integration of different ethical values from within different cultural ecosystems.
4. A recognition of the role of internal self-regulation alongside and external regulatory action, to promote a reflective, continuously adaptive, internally self-regulated moral code. This has advantages over direct regulatory oversight which can be difficult to maintain in a way that remains to date and relevant to the fast-paced developments in the neurotechnology sector.
5. The compatibility of standards and regulatory requirements across different sectors and jurisdictions can encourage responsible self-regulation whilst help secure predictability in routes to market.
6. Continuous engagement with the public, policy makers and regulators is necessary to secure acceptability of novel applications that are potentially disruptive.

Under the umbrella of neuroethics, a number of frameworks and approaches are currently being developed in academic, policy, and company settings. One emerging framework is AIM ([A] anticipate and articulate, [I] implement and integrate, and [M] monitor and measure), presented at the Shanghai Workshop by Judy Illes (Professor of Neurology and Canada Research Chair in Neuroethics, University of British Columbia) as one possible way forward (Illes, 2018[74]):

- **Anticipate and articulate**: for neurotechnology to advance ethically, ethically tenable values and goals must be predefined and articulated. These include the goals of inclusivity discussed by Tan Lee (CEO and Founder, EMOTIV) and post-mortem outreach discussed by Tom Insel (Co-founder and President, Mindstrong Health) that bridge the leap from the laboratory to life. Inclusivity, much like Value Sensitive Design (Friedman et al., 2013[75]) embraces the voices of all stakeholders – inventors to end-users of all backgrounds and ages – early on in the design process and mitigates biases that can be introduced when developers work in professional, gender, and cultural isolation. Post-mortem outreach can be understood to span the full range of planning for the dissemination and sales of successful products, as well as the sharing of knowledge about unsuccessful neurotechnological attempts,

whether those involve failed technical design, poor uptake, harm, and even lack of financial interest from potential investors.

- **Implement and integrate**: the focus of this aspect of the AIM framework is on trust that is achieved when ethical targets are anticipated and values are well-articulated. Ethical benchmarks are set, and strategies to maintain them are implemented and integrated. This aim ensures a focus on proper planning and execution of trials and testing of devices, with realistic recruitment and business plans that ensure funding-to-completion and follow-up of participants as needed (Eaton, Kwon and Scott, 2015[76]). For clinical trials, it ensures that they are stopped only when results are clearly insignificant, there is harm to subjects from adverse events, a deficient protocol design renders trial continuation futile, or there is authentic inability to recruit human subjects. Adherence to this aim limits unethical abandonment of trials midstream due, for example, to change in investor interests, funding, shrinking research budgets, mergers and acquisitions, emergence of competitive products, pressures to end unproductive programs, defensive manoeuvres by competition, supply failures, or catastrophic events. It also embraces efficacy and trial change when, for example, a device is modified to improve its performance or to suit a new target population, or moves into the real-world clinic or home setting.
- **Monitor and measure**: the concept of ethical reproducibility and informed risk – over informed consent – are key variables to measure and monitor (Anderson, Eijkholt and Illes, 2013[77]). In animal testing, for example, ethical reproducibility pertains to well-established requirements for reporting, and strategies used to select models, procedures to mitigate pain, and approaches to minimize the numbers required for robust experimental results. As proposed more explicitly for human experimentation, this concept pertains to reporting of strategies to assure the capacity of a prospective participant to consent to a study, especially in cases involving the greater acquisition of cognitive autonomy (youth) or diminishing cognitive capacity (older adults), steps to mitigate risks to individuals and third parties, steps to maximize benefit in the short and long term, and steps to assure justice and access. Communication is the key to reproducibility in this context. All stakeholder must be vested in measuring and monitoring success, failure, and benefit and harm and appreciate them in all the local or global environments in which they may occur. The internal desire for professional self-regulation and outward communication of them are expressions of integrity. However, it should be noted that self-regulation maybe insufficient whenever fundamental rights are concerned. Moreover, self-regulation would not shield those that abide by it from possible liabilities since legal principles do still apply.

Various other approaches are currently being developed by established companies and start-ups. For example, the Canadian start-up Aifred developed the "meticulous transparency" framework, which aims to support AI developers, civil society and regulatory bodies to evaluate AI technologies for their capabilities and the intentionality. Meticulous transparency provides stakeholders with a complete description of the purpose, scope of use, projected benefits and risks, and data sources of the AI application upstream its development. "Meticulous transparency shifts the focus of ethical evaluation from the technology itself to instead why it is being built, and potential consequences." (Benrimoh et al., 2018[49]).

Similar to an ethics board, the "meticulous transparency" framework demands AI developers to publicly document and explain: (1) establish a rationale for a project (intentions); (2) defend the methods (data sources and interpretability); (3) discuss positive and negative impacts (consequences).

This framework has six evaluation steps, aimed at ensuring that developers consider the full range of ethical concerns prior to commencing development:

1. A complete description of the purpose of the product. This refers to declaring the intentionality behind the project- focusing on consequences and purpose rather than simply technical specifications and capability.
2. Scope of use. This refers to defining where and with which populations the tool should be operating.
3. Data sources and bias control. This refers to ensuring that the application is being trained using appropriate data given the intended purpose and scope of use, which is critical when attempting to reduce bias.
4. Human interpretability. This refers to having decisions explainable enough that a human operator would be able to understand them. This does not mean perfect explainability – just to a degree that is appropriate to the field. For example, within medicine risk factors are often used from the literature when making certain decisions, even when these risk factors are not completely understood. This is similar to understanding the key input features of an AI model, even if their high-level interactions with other features are difficult to explain.
5. Projected risks and benefits. This refers to a process of assessing risks and benefits of the application, considered from many different perspectives (social, economic, social justice etc.).
6. Monitoring and contingency plans for Adverse Events. Finally, makers of AI and neurotechnology products could be considered as to have the same responsibility as drug developers, who must continue to monitor their products for adverse events and unintended consequences.

6.3. Emerging practices for responsible innovation in business settings

Leading companies in, e.g. neurotechnology, machine-learning, robotics, and the various digital technologies are well-positioned to identify and tackle critical issues by interacting with researchers, users and investors alike. In fact, workshop participants emphasized that "the science needs to be done right" to ensure ethical viability, governability, and social desirability of emerging technologies and to manage expectations and hypes. However, while many companies are ready to engage questions of responsibility head-on, they frequently lack the tools and framework to do so within their business settings. Recognising that the social and ethical issues raised by the diversity of novel technologies fall squarely in-between public and private sector responsibilities as part of the innovation process can help ensure socially desirable outcomes and contribute to the robustness and sustainability of products and services in this promising field.

Various good practices have already begun to emerge from within neurotechnology companies as well as related technology domains such as AI, gene editing, nanotechnology, or synthetic biology. An overview of the different ex-ante (pre-emptive) and ex-post approaches by larger technology industries was provided at the Shanghai Workshop by

Gary Marchant (Regents Professor, Center for Law Science & Innovation, Arizona State University) and is summarized in Table 4 (Marchant, 2016[78]).

Table 4. Examples of governance frameworks for emerging technologies at companies

Mechanism	Example
Company-NGO Partnership	DuPont-EDF Nanotechnology Risk Framework
http://www.nanoriskframework.org/	
Responsible Use Guidelines	Coalition for Responsible Gene Editing
http://geneediting.foodintegrity.org/responsible-use-guidelines/	
Risk Mitigation Checklist	Ethical OS
https://ethicalos.org/	
Downstream Product Stewardship	Ginkgo Bioworks, Bayer Company
https://media.bayer.com/baynews/baynews.nsf/id/Bayer-Ginkgo-Bioworks-unveil-joint-venture-Joyn-Bio-establish-operations-Boston-West-Sacramento; https://spectrum.ieee.org/the-human-os/biomedical/ethics/synthetic-biology-behemoth-aims-to-police-its-own-industry	
Industry Best Practices	Future of Privacy Forum
https://fpf.org/2018/07/31/future-of-privacy-forum-and-leading-genetic-testing-companies-announce-best-practices-to-protect-privacy-of-consumer-genetic-data	
Public Engagement	Gene Drives
https://doi.org/10.1002/hast.808	
Request Government Regulation	Microsoft Facial Recognition Technology
https://blogs.microsoft.com/on-the-issues/2018/07/13/facial-recognition-technology-the-need-for-public-regulation-and-corporate-responsibility/	
Data Responsibility	IBM's Principles for Trust and Transparency
https://www.ibm.com/blogs/policy/trust-principles/	
Patent Licensing	Broad Institute Principles for Disseminating Scientific Innovation
https://www.broadinstitute.org/principles-disseminating-scientific-innovations; https://ssrn.com/abstract=2897574	
External Monitor	Volkswagen Compliance Monitor
https://www.reuters.com/article/us-volkswagen-emissions-monitor/u-s-monitor-seeks-more-transparency-from-vw-over-emissions-idUSKCN1LC0RW	
Certification Programmes	Responsible Care System, American Chemistry Council
https://responsiblecare.americanchemistry.com/Management-System-and-Certification/	

Source: Prof. Dr. Gary E. Marchant, Faculty Director and Regents Professor, Center for Law Science & Innovation, Arizona State University, Tempe, USA; presentation at Shanghai Workshop, adapted.

A range of examples for such instruments and good practices that can help support responsible innovation within the private sector were further elaborated by Sebastian Pfotenhauer (Linde Professor of Innovation Research, Munich Center for Technology in Society and TUM School of Management, Technical University of Munich) and Nina Frahm (Munich Center for Technology in Society and Harvard Kennedy School):

- **Appoint responsible innovation officers and boards.** Consistent attention to questions of responsibility requires human resources and organizational capacity. Several neurotechnology businesses, including the digital phenotyping start-up

Mindstrong Health, have recently appointed advisory boards consisting of domain experts, regulatory experts, and social scientists. Such dedicated Responsible Research and Innovation (RRI) or ethical, legal and social issues (ELSI) boards can help the company monitor and support technology development in socially desirable directions, and anticipate or co-shape emerging regulations. Moreover, companies can attune their CSR and R&D departments to questions of responsible innovation. Dedicated personnel can help bridge traditional organizational boundaries. However, particularly for young (or small) innovation-oriented business, an external advisory board might be even more important than traditional CSR units.

- **Develop principles and guidelines.** A number of organizations have recently released principles or guidelines that focus on questions of responsible innovation, but also professional associations like Institute of Electrical and Electronics Engineers (IEEE) or the Coalition for Responsible Gene Editing. Principles may entail high-level management commitments for entire companies or projects; they may also be part of the identity of a start-up (e.g. the commitment to collect minimal data). They can combine elements of both of "responsible development" and "responsible use" of novel technology. One challenge is that at present, principles tend to be rather abstract and hence hard to implement in concrete and measurable ways. However, this challenge is not unique, but is shared by e.g. initiatives to enhance sustainability. Difficult operationalization notwithstanding, principles can serve as a useful moral compass.

- **Responsible technology transfer.** The transition from the lab to the commercial stage is a critical juncture for questions of responsibility (Eppinger and Tinnemann, 2014[79]; Gwizdała and Śledzik, 2017[80]) Many researchers and innovators take great interest in the future use of their invention, even when realized without their direct participation, e.g. through licensing agreements. University technology transfer offices typically operate under incentive structures that emphasize numbers of patents and licences, or the amount of licensing returns for the host institution. Responsible transfer metrics could include considerations of social benefits and impact (e.g. free licensing to developing countries), equity (e.g. patent pools), and anticipatory governance (e.g. as part of business plans), and adjust incentives and transfer contracts accordingly (e.g. required RRI boards for start-ups).

- **Strategic partnerships.** Public-private partnerships have proven effective instruments for providing public services or tackling societal challenges through combined investments (OECD, 2015[81]; Roehrich, Lewis and George, 2014[82]). Moreover, recent initiatives around public procurement of innovation have been used create nascent markets and steer innovation activity in directions of public value as defined by governments through "challenges" and specific conditions. For example, public procurement calls in robotics are currently aiming to address infrastructural maintenance tasks such as sewer and bridge inspections. Neurotechnology companies can seek to develop strategic partnerships and alliances with research institutions, governmental and non-governmental organizations to anticipate and tackle responsibility issues.

- **Socially responsible investment & certification.** Especially for start-ups, key decisions about company and marketing strategy are typically greatly shaped by their investors. Conference participants suggested that careful selection of one's investors is instrumental for addressing questions of social responsibility. Recent

trends towards sustainable investments and "green bonds" might offer a model for novel forms of "responsible investment" (Kurtz, 2009[83]). Such a development could be supported by new standards or certifications. While the European Union has developed various RRI checklists and standards for responsible research and innovation in the public sector, they do presently not exist for private sector settings. Iatris and Schroeder (2016[84]) recently investigated how existing CSR standards and certification (such as ISO9001 or IS45001) could be mobilized to include aspects of RRI in a more comprehensive manner.

- **Diversify hiring practices.** Many tech companies are increasingly hiring social scientists and humanities experts to address a broader and perhaps more socially conscious set of perspectives on innovation. This can help to provide more socially inclusive perspectives on the benefits and risks of neurotechnology, and anticipate potential controversies.
- **Use test beds and regulatory "sandboxes" to co-create technology and regulation.** Companies and innovation scholars are increasingly emphasizing the need to develop innovations in real-world settings that can anticipate and respond to use patterns, social uptake, concerns, and potential regulatory issues. Novel instruments such as test-beds, living laboratories and regulatory sandboxes enable testing in spatially confined, experimental settings prior to broader rollout, frequently with some form of "co-creation." These instruments can also be employed to co-develop appropriate rules and regulations in tandem with the technology, as currently seen in cases of autonomous driving and robotics. For neurotechnology, there are opportunities to investigate applications with selected populations (e.g. local mental health patients) together with the participation of public bodies to gauge regulatory needs.

6.3.1. Corporate Social Responsibility (CSR)

In organizational terms, questions of responsibility are traditionally the domain of Corporate Social Responsibility (CSR), an important source of soft law, which has developed into a lively area of academic scholarship and diverse practice (Crane et al., 2009[85]; Idowu and Louche, 2011[86]). Many medium and large enterprises have adopted CSR practices and organizational units tasked with CSR. A wide range of international standards, best practice, and instruments are available, including OECD Guidelines for Multinational Enterprises (2011[87]) and the UN Guiding Principles on Business and Human Rights (UN Human Rights, 2011[88]).

Yet, questions of responsible innovation, i.e. the social, ethical, and legal challenges arising from the development of high-tech products, have largely remained outside the CSR purview, which has been concerned more with matters of worker and human rights, local communities, or environmental externalities, e.g. in the mining sector or globalized manufacturing. Workshop participants remarked that the organisational barriers between CSR and Research and Development units tend to be high. Moreover, many companies at the forefront of disruptive innovations are start-ups that lack the organisational capacity, resources, experience, or time to make CSR a priority. Yet, many CSR dimensions apply equally to responsible innovation questions:

- **Externalities:** like other forms of economic activity, innovation can create negative externalities and spill overs, such as in the democratic implications of digital social media or autonomous driving. Anticipating, managing and potentially internalizing these externalities will be a key issue of responsible innovation.

- **Public trust and social licence to operate:** trust in the integrity and intentions of innovative companies, and in the technologies they develop, are key for business success and sustainability. As recent controversies around social media data leaks, gene patents, or automotive emissions testing underscored, the social licence to operate for a company is a central asset of business model in any innovative firm.
- **Socio-cultural embedding and regulation:** like CSR practices, responsible innovation practices will differ across countries and communities based on social values, norms, economic conditions, and the political and institutional landscape. International RI practices will have to balance the desire for uniform global standards with socio-cultural idiosyncrasies.
- **Corporate scientific citizenship:** good corporate citizenship entails using rights and responsibilities for innovation with a view towards other citizens and the public good.
- **Shareholder and stakeholder accountability:** a key CSR debate has been between advocates of a narrow definition of value creation as shareholder value vs. a broader sense of accountability to all societal stakeholders. Similar arguments apply to responsibility in innovation, where an investor's interest in financial returns (e.g. Venture Capital funding a start-up) has to be balanced against broader definitions of public value.

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Annex B.

Agenda OECD Workshop

"Minding Neurotechnology: delivering responsible innovation for health and well-being"

6-7 September 2018, Shanghai, People's Republic of China

The objectives of the Shanghai Workshop are:

1. Promote a deeper dialogue among business leaders, investors, policy makers, social scientists, and practitioner communities to enable desirable social outcomes and benefits of neurotechnology.
2. Enrich current discussions of the social implications of neurotechnology on both short and long-term time horizons by hearing from those engaged in bringing products to market.
3. Better understand how considerations of responsible innovation can improve the sustainability of business models in novel neurotechnology.

Day One (Thursday, 6 September 2018)

08:30-09:00 ► **Registration**

Venue: Renaissance Shanghai Putuo Hotel

09:00-09:30 ► **Welcome messages & introduction to workshop**

Workshop Moderator: Prof. Dr. Jialin Charles Zheng, Professor of Regenerative Medicine and Neuroscience, Dean, Tongji University School of Medicine, Shanghai, People's Republic of China

- Mr. Dominique Guellec, Head, Science and Technology Policy Division, Directorate for Science, Technology and Innovation, OECD, Paris, France
- Ministry of Science and Technology of the People's Republic of China (MOST)
- Dr. Xinmin Zhang, Director General, China National Center for Biotechnology Development (CNCBD), People's Republic of China
- Prof. Dr. Jie Chen, President of Tongji University, Shanghai, People's Republic of China
- Mr. Ik-hyeon Rhee, President Korea Legislation Research Institute (KLRI), Republic of Korea

09:30-09:55 ► **Keynote**

Ms. Tan Le, CEO, EMOTIV, San Francisco, USA

09:55-10:20 ► **Keynote**

Prof. Dr. Mu-ming Poo, Member of the Chinese Academy of Sciences, Director, Institute of Neuroscience, Chinese Academy of Sciences, Director, CAS Center for Excellence in Brain Science and Intelligence Technology, People's Republic of China

10:20-10:50 ► **Coffee break**

10:50-12:40 ► **Session 1**

Neurotechnology innovation from the bottom up: strategies for product development at major brain research initiatives

Chair: Prof. Dr. Linda Richards, Deputy Director (Research), Queensland Brain Institute, Australia

Panellists:

- Dr. A. Lyric Jorgenson, National Institutes of Health (NIH), Lyric A. Jorgenson, Deputy Director, Office of Science Policy, Office of the Director, USA
- Dr. Sung-Jin Jeong, Principal Researcher/Director, Neuronal Development and Disease Department, Brain Research Policy Center Korea Brain Research Institute, Republic of Korea
- Dr. Dekel Taliaz, CEO & Co-Founder, Taliaz Ltd, Co–founder, Vice President, Tech division of Israel Brain Technologies, Israel
- Prof. Dr. Shigeo Okabe, Brain/MINDS Program Supervisor, Graduate School of Medicine, The University of Tokyo, Japan
- Prof. Dr. Qingming Luo, Vice President, Huazhong University of Science and Technology, People's Republic of China

This first session focuses on the translation of knowledge emerging from major brain research initiatives into novel neurotechnologies for health and well-being. In order for those technologies to be integrated into society, they need to be developed for markets and broadly disseminated beyond the laboratory or company where they originated. Health innovation and technological development are expressed goals of some major public funding efforts and national brain initiatives, with company formation being imagined as one key to achieving those goals.

Discussion questions:

1. What are the current trends for neurotechnology innovation across the major 'brain initiatives'? What are the funding opportunities for the dissemination and translation of research?
2. For the 'brain initiatives' seeking to spur innovation: what are best practices for attracting investment, encouraging public-private sector collaboration, and translating research into marketable products?
3. What mechanisms are in place to ensure spin-outs and future products meet ethical, social standards?

12:40-13:40 ► **Lunch**

13:40-14:05 ► **Keynote**

Dr. Tom Insel, Co-Founder and President, Mindstrong Health, Palo Alto, CA, USA

14:05-14:20 ► **Session lead-in: "Neurotechnology ventures"**

Mr. Jordan P. Amadio, M.D., M.B.A., Neurosurgeon, Technology Innovator, Start-up Investor/ Strategist, Austin, Texas, USA

14:20-16:05 ► **Session 2**

Making innovation work: addressing the challenges of commercialisation in disruptive technology

Chair: Mr. Jordan P. Amadio, M.D., M.B.A., Neurosurgeon, Technology Innovator, Start-up Investor/ Strategist, Austin, Texas, USA

Panellists:

- Dr. Graeme Moffat, VP of Scientific & Regulatory Affairs, MUSE, Toronto, Canada
- Dr. David Benrimoh, CEO, Aifred Health, Montreal, Canada
- Dr. Moonkyo Chung, Korea Technology Finance Corporation (KOTEC), Deputy Director, Seocho Technology Appraisal Center, Republic of Korea
- Dr. Oh-hyoung Kwon, Partner, FuturePlay, Republic of Korea
- Ms. Yifei Fan, Business Development Manager, AXA Lab Asia, Shanghai, People's Republic of China
- Prof. Dr. Luming Li, Professor of Biomedical Engineering and Neuromodulation Technology, Tsinghua University, Beijing, People's Republic of China
- Dr. Yunting Liu, Commercial & Strategy Director, Tencent Medical, People's Republic of China
- Dr. Chris Thatcher, President and CEO, NeuroStar, USA

This session will focus on the formation and development of small and medium sized enterprises and their engagement with key partners: public research institutions and the private investment sector. Panellists will discuss the current state of play in their technologies, business models and challenges.

Discussion questions:

1. What are the unique challenges and opportunities for start-up companies and SMEs in neurotechnology innovation in terms of, e.g., market size, investment, ethics, and regulation?
2. What is the landscape of private investment in the arena of neurotechnology?
3. What is the role of academic entrepreneurs in the commercialisation of techno-creative innovations?

16:05-16:25 ► **Coffee break**

16:25-16:40 ► **Session lead-in**

Prof. Dr. Guoyu Wang, Professor of Philosophy, Fudan University, People's Republic of China

16:40-18:30 ► **Session 3**

Identifying gaps in neurotechnology governance: potential roles of the market and the public sector to ensure 'technology robustness'

Co-Chairs: Prof. Dr. Guoyu Wang, Professor of Philosophy, Fudan University, P.R. China; Mr. John Clarkson, Senior Vice President and Chief Operating Officer, Ontario Brain Institute, Toronto, Canada

Panellists:

- Dr. Mariarosaria Taddeo, Research Fellow, Deputy Director, Digital Ethics Lab, Oxford Internet Institute, University of Oxford, Turing Fellow, Alan Turing Institute, London, Oxford, UK
- Mr. Junkil Been, Co-founder, Chief Executive Officer, Neurophet, Republic of Korea
- Dr. Marcello Ienca, Research Fellow, Health Ethics & Policy Lab, Department of Health Sciences and Technology, ETH Zürich, Switzerland
- Mr. Alex Ni, MBA, CPA, CMA, CTO, Avertus, Toronto, Canada
- Dr. Laura Y. Cabrera, Assistant Professor, Neuroethics, Michigan State University, Center for Ethics & Humanities in the Life Sciences, USA
- Dr. Andrea Bertolini, Assistant professor Private Law, Dirpolis Institute, Adjunct Professor, Private Law, University of Pisa, Italy

The third session will raise potential governance issues associated with emerging neurotechnologies that deserve shared consideration given their public attention as well as potential economic and social implications. Concerns about privacy and misuse of brain data have become more tangible in the wake of recent privacy breaches in the social networking community. Other governance issues are raised when products intended for clinical use are used in non-therapeutic settings. Given the limited experiences with some novel neurotechnologies: how can companies, investors, and insurers anticipate the potential unintended use, broader societal effects, misperception and backlash? How do they engage the goal of "appropriate use", data privacy, and integrity in neurotechnologies?

Discussion questions:

1. Understanding the grey areas in neurotechnology: what are the key gaps, risks and uncertainties within businesses, and at the intersection of the public and private sector?
2. Are governance tools such as consumer protection laws, liability rules, post-marketing surveillance, and current ethical frameworks sufficient to promote public trust and technology robustness?
3. What are the best practices to learn from "early adopters" that support technology validation?

19:00 ► **Dinner**

Day Two (Friday, 7 September 2018)

08:45-09:00 ► **Opening Day Two**

Workshop Moderator: Dr. Pingping Li, Associate Professor, Deputy Director, Division of Public Health, China National Center for Biotechnology Development (CNCBD), People's Republic of China

► **Comment**

Prof. Dr. Gang Pei, Member of the Chinese Academy of Sciences, Former President of Tongji University, Shanghai Institute of Biochemistry and Cell Biology, Chinese Academy of Sciences, People's Republic of China

09:00-09:15 ► **Session lead-in: "Challenges in the governance of emerging technology"**

Prof. Dr. Gary E. Marchant, Faculty Director and Regents Professor, Center for Law Science & Innovation, Arizona State University, Tempe, USA

09:15-11:00 ► **Session 4**

Building responsible innovation: frameworks and best practices in the private sector

Chair: Prof. Dr. Judy Illes, Canada Research Chair in Neuroethics, Professor of Neurology, Department of Medicine, Director, Neuroethics Canada, The University of British Columbia, Vancouver, Canada

Panellists:

- Prof. Dr. Karen Rommelfanger, Assistant Professor, Department of Neurology, Assistant Professor, Department of Psychiatry and Behavioral Sciences, Emory University, Atlanta, USA
- Prof. Dr. Sebastian Pfotenhauer, Professor of Innovation Research - Innovation, Society & Public Policy Group, Munich Center for Technology in Society, Technical University of Munich, Germany
- Dr. Xiaodong Tao, Vice Precedent, IFLYTEK CO., LTD., President of iFLY Health, People's Republic of China
- Prof. Dr. Yizheng Wang, Researcher, Huashan Hospital, Fudan University, People's Republic of China
- Dr. Tom Insel, Co-Founder and President, Mindstrong Health, Palo Alto, CA, USA
- Ms. Tan Le, Founder, Chief Executive Officer, Emotiv, San Francisco, USA
- Prof. Dr. Adrian Carter, Associate Professor, Head, Neuroscience and Society Group, Monash Institute of Cognitive and Clinical Neurosciences, Monash University, Australia
- Prof. Dr. Ricardo Andrés Chavarriaga Lozano, Ecole Polytechnique Fédérale de Lausanne, CNBI - Chair in Brain-Machine Interface, Geneva, Switzerland

In this session, panellists will focus on the modes through which ethics and social responsibility can make a positive impact on brain research and neurotechnology development. A mixed group of innovators, representatives from major 'brain initiatives', and other experts discuss how forms of upstream responsibility can contribute to downstream profitability and health impact. Some brain research initiatives and businesses within neurotechnology and related fields like AI have sought to integrate elements of social responsibility and ethics into their technology transfer,

business practices, R&D, and corporate governance.

Discussion questions:

1. What are the strategic approaches and best practices to align disruptive neurotechnology with societal needs? How can responsibility frameworks complement regulation and support the robustness of products in markets?
2. What strategies are used by major brain initiatives and companies to help promote transparency, trust, and positive societal outcomes?
3. How can ethical, legal, and social considerations of neurotechnology innovation strengthen the ties between public research, investors, companies, and insurers?

11:00-11:20 ► **Coffee break**

11:20-12:30 ► **Session 5**

Exploring the potential role of policy makers in delivering responsible innovation for health and well-being

Chair: Dr. David Winickoff, Senior Policy Analyst, Secretary, Working Party on Bio-, Nano- and Converging Technologies (BNCT), Science and Technology Policy Division, OECD, Paris, France

Panellists:

- Dr. Françoise D. Roure, Chairperson of the Committee "Safety, Security and Risk", French Ministry of Economy and Finance High Council of Economy, Paris, France
- Dr. Seunghye Wang, Research Fellow, Office of Global Legal Research, Korea Legislation Research Institute, Republic of Korea
- Prof. Dr. Xian-En Zhang, Principal Investigator, Institute of Biophysics, Chinese Academy of Sciences, Former Director of the Basic Research Department, Ministry of Science & Technology (MOST), People's Republic of China
- Dr. Isabella Beretta, Scientific Advisor International Research Organisations, Federal Department of Economic Affairs, Education and Research EAER, State Secretariat for Education, Research and Innovation SERI, Berne, Switzerland
- Dr. A. Lyric Jorgenson, National Institutes of Health (NIH), Deputy Director, Office of Science Policy, Office of the Director, USA
- Mr. Hugh Whittall, Director at Nuffield Council on Bioethics, UK

Participants reflect on the potential role of policy makers and innovators in advancing responsible innovation in neurotechnology. The OECD is developing Principles for responsible development and use of novel neurotechnologies for health-related applications.

12:30-13:00 ► **Summary, conclusions, and outlook**

Dr. David Winickoff, Senior Policy Analyst, Secretary, Working Party on Bio-, Nano- and Converging Technologies (BNCT), Science and Technology Policy Division, OECD, Paris

13:00 ► **End of workshop**