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WORKING PAPER

DELIVERING RESPONSIBLE NEUROTECHNOLOGIES GOVERNANCE

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GENERAL INTRODUCTION

Neurotechnologies constitute a fast-evolving field of measuring, analysing, and potentially modifying activities of the human nervous system. They include devices and capabilities such as neuroprostheses, neuromodulation and brain-machine interfaces. In medical and non-medical fields, they may have profound implications for fundamental human experiences, potentially transforming notions of identity, autonomy, privacy, and cognitive agency.[1]

Capabilities developed to date include devices with functionalities that encompass brain-machine interfaces (BCIs), neuromodulation and neuroprosthetics. In both clinical and non-clinical settings, these advancements could render far-reaching consequences across a range of our human experiences, likely leading to the reordering how we conceptualise fundamental facets of human agency relating to our autonomy, spatial privacy, cognitive agency and mobility.[2] Given such potential, their use raises ethical issues, e.g. boundary-drawing and harm-benefit balancing. Whilst public debate over neurotechnologies has highlighted concerns, frequently less prominent in the ethical and legal discourse have been their potentially profound positive impacts. Neurotechnologies may radically improve quality of life for marginalised and minority groups and provide broader possibilities for the enjoyment of human rights often affected by health-related limitations.

This study examines how to improve these possibilities and analyse what novel, yet foreseeable challenges they present for affected stakeholder groups. For example, how might neurotechnologies affect representation, autonomy, or the privacy of marginalised groups, people with functional diversity, or the severely ill? Given regional legislative regimes and regulation, along with the framework provided by international conventions, this work elucidates the ethical and legal boundaries of neurotechnologies and their justifiability from the perspective of affected stakeholders. It examines how fostering patient engagement through appropriate consultative mechanisms can facilitate the reconciliation of competing values. Given fast-paced scientific advancement, the discourse on neurotechnologies must be informed by stakeholder perspectives (the next empirical step). Absent this engagement, insights into whose, and which, interests (e.g. cognitive autonomy, accessibility, equality of access, cultural and social acceptance) are at risk. Moreover, conflicting values may also require resolution so as to ensure neurotechnologies reach their full potential.

THE RIGHT TO PRIVACY: IMPLICATIONS OF NEUROTECHNOLOGY DEVELOPMENTS

The rapid advancement of neurotechnologies represents one of the most significant scientific frontiers of the 21st century, fundamentally challenging our understanding of human cognition, consciousness, and the boundaries of privacy. These emerging technologies, ranging from brain-computer interfaces (BCIs)[3] to neural monitoring devices and cognitive enhancement systems,[4] promise revolutionary applications in medicine, education, and human performance optimization.[5] However, they simultaneously raise unprecedented questions with respect to many facets of mental privacy—a domain largely considered the last bastion of individual autonomy and personal sanctuary.[6]

The concept of privacy has evolved considerably throughout human history, adapting to technological innovations from the printing press to digital surveillance systems.[7] Yet neurotechnologies present a qualitatively different challenge: the potential for direct access to human thoughts, emotions, memories, and intentions.[8] This development necessitates a fundamental re-examination of the right to privacy within legal, ethical, and philosophical frameworks that were not initially designed to address such intimate technological intrusions.

This analysis explores the complex intersection between neurotechnological advancement and privacy rights, examining both the transformative benefits these technologies offer and the profound risks they pose to cognitive liberty and mental autonomy. The stakes of this discussion extend beyond individual privacy concerns to encompass broader questions of human dignity, democratic governance, and the future of human agency in an increasingly connected world.

OVERVIEW OF CONTEMPORARY NEUROTECHNOLOGY DEVELOPMENTS

Brain-Computer Interfaces and Neural Prosthetics

Modern BCIs have progressed from experimental laboratory devices to commercially viable medical interventions, enabling direct communication between the brain and external devices. Researchers based at enterprises including Neuralink, Synchron, and Blackrock Neurotech have developed sophisticated systems that enable monitoring of neural signals with increasingly remarkable precision.[9] These devices have already for improvements in mobility for allow paralyzed individuals, and to control computers, robotic limbs, and communication devices, representing a paradigm shift in assistive technology.[10]Therapeutic applications extend beyond motor control to include treatment of depression, epilepsy, and Parkinson's disease through deep brain stimulation and closed-loop neurostimulation systems.[11] These interventions demonstrate neurotechnologies' capacities to not only interpret neural signals but also to modify brain activity, raising questions as to the boundaries between an individual's treatment and enhancement.

Neural Monitoring and Neuroimaging Technologies

Advanced neuroimaging techniques, including high-resolution fMRI, optogenetics, and emerging technologies such as ultrasonic neural interfaces, provide unprecedented increasingly nuanced perspectives on brain activity.[12] These non-invasive or minimally invasive methods can detect patterns associated with thoughts, emotions, and decision-making processes, potentially enabling applications in areas such as lie detection, assessment of a person's mental state, and monitoring of cognitive load.[13] In addition, consumer-grade neurotechnologies devices already on the market, such as EEG headsets, claim to assist in activities such as meditation, focus enhancement, and to enable 'brain training', supposedly democratizing access to capabilities while simultaneously expanding the data collection footprint of neurotechnology into everyday life.[14]

Cognitive Enhancement and Neuropharmacology

The convergence of neurotechnology with pharmaceutical interventions and stimulation techniques has created new possibilities for potential cognitive enhancements. These technologies promise to augment memory, attention, learning capacity, and emotional regulation, potentially transforming educational and professional environments.[15]

BENEFITS OF NEUROTECHNOLOGIES FOR SOCIETY AND INDIVIDUALS

Medical and Therapeutic Uses

Neurotechnologies offer transformative potential for treating previously intractable neurological and psychiatric conditions. Patients with spinal cord injuries, ALS, and locked-in syndrome have regained communication abilities and motor control through BCI systems.[16] Deep brain stimulation has provided relief for individuals with treatment-resistant depression, obsessive-compulsive disorder (OCD), and movement disorders, offering hope where prior interventions have either failed or provided limited improvement in patients' conditions.[17]

The potential for a precision medicine approach enabled by neurotechnology allows for personalized treatment protocols based on individual neural patterns, potentially improving therapeutic outcomes while reducing side effects.[18] Real-time neural feedback systems can also potentially optimise treatment delivery and adjust interventions based on ongoing monitoring of neural activity.[19] For individuals with disabilities, neurotechnologies potentially offer unprecedented opportunities for treatment to improve mobility, independence and also social participation.[20] Development in neural prosthetics also promise advancements in the treatment and restoration of sensory capabilities, enabling complex motor control, improved vision, and facilitating communication in ways that traditional assistive technologies have heretofore provided only limited improvements.[21]

Neurotechnologies can also provide researchers with powerful tools for understanding brain function, consciousness, and the neural basis of human behaviour. This enhanced understanding could lead to breakthrough treatments in other areas of medicine such as mental health, neurodevelopmental disorders, and age-related cognitive decline, potentially benefiting millions of individuals worldwide.[22]

The technology-based objective measurement of mobility impairments has evolved considerably, bringing forth the promise of substantially improving the diagnostic, monitoring and therapeutic landscape for a number of different diseases such as Parkinson's, dementia and Alzheimer's. Advances in artificial intelligence (AI), sensors, mobile communications, cloud computing, advanced analytics, and the Internet of Things (IoT) are amongst the innovations that continue to reshape healthcare and the treatment of patients with chronic, complex and fluctuating disorders. For example, patients who have suffered a stroke or have Parkinson's disease often experience difficulty walking or are at high risk of falls. Fortunately, recent innovations in medical technologies have provide patients with treatments that can alleviate symptoms and significantly improve mobility and patient's safety.

In parallel, advancements in artificial intelligence (AI) and its application to behavioural biometrics now also present scope for innovation in the evolution of human activity recognition (HAR) in surveillance systems. Novel technologies allow for the analysis of physical and behavioural characteristics to continuously track and monitor activities for patterns of unusual behaviour. Conventional surveillance depends heavily on human observers, which requires significant resources, introduces errors, and takes considerable time. Behavioural analysis has ostensibly been developed as an effective response to these challenges in scaling security monitoring applications. Furthermore, biometric credentials are increasingly being leveraged for authentication and verification due to their advantages over traditional methods.

This synchronous maturation of such capabilities now presents unprecedented challenges. The intersection of the deployment of therapeutic neurotechnologies with continuously more sophisticated behavioural monitoring raises important questions as to the both the efficacy and reliability of distinguishing different individuals based on existing conceptualisations of human mobility patterns. The scope of this paper focuses narrowly on wearable medical devices for continuous monitoring of movement disorders and the treatment of Parkinson's disease, essential tremor, and other movement disorders, and asks how such therapeutics may influence the operations of biometric surveillance. Key concerns arise in terms of how interactions between these technologies impact a number of interdependent human rights.

PRIVACY RISKS AND CONCERNS

Mental Privacy and Cognitive Liberty

The most fundamental privacy concern raised by neurotechnologies involves the potential violation of mental privacy—the right to keep one's thoughts, memories, and mental processes private. Unlike traditional surveillance technologies that monitor external behaviours or communications, neurotechnologies could potentially in the future access the content of consciousness itself, including involuntary thoughts, emotional states, and subconscious processes.[23]

This capability raises questions about cognitive liberty—the right to mental self-determination and freedom from unwanted mental intrusion. The involuntary nature of many neural signals means that individuals may be unable to control what information is collected, fundamentally challenging traditional notions of prior and informed consent, and voluntary disclosure.[24]

Data Protection and Data Security

Neural data presents unique data security and data protection challenges due to the sensitivity of the information it relates to, creating particular concerns for personal data collection, processing, data transfers and retention.[25] The theft or misuse of neural data could enable unprecedented forms of fraud and other harms, including profound risks such as psychological manipulation by malign actors.

The storage and transmission of neural data across networks and devices create multiple points of vulnerability where malicious actors could intercept or corrupt brain-derived information. The consequences of such breaches extend beyond individual privacy to include potential manipulation of democratic processes, commercial exploitation, and social control.

Implications for Surveillance and Social Control

Neurotechnologies could enable new forms of surveillance, both by State and corporate entities, that penetrate deeper into individual autonomy than any previous technology. Governments could leverage neural monitoring to detect dissent, attempt to predict subversive or criminal behaviour, or enforce ideological compliance.[26] Businesses might attempt to exploit neural data for manipulation of consumer behaviour and preferences for goods and services.[27] The potential for coercive deployment of neurotechnologies in institutional settings—such as prisons, schools, or workplaces—raises concerns about involuntary mental monitoring and the erosion of fundamental human rights. The integration of neurotechnology with existing surveillance infrastructure could create comprehensive monitoring systems that track both external behaviour and internal mental states.

LEGAL AND REGULATORY CHALLENGES

Challenges to Current Legal Frameworks

Existing privacy laws and regulations have evolved primarily to address and regulate traditional forms of data collection, processing and retention, leaving significant gaps in certain legal frameworks with regard to data protection for information derived from monitoring using neurotechnologies. Current frameworks typically require explicit prior and informed consent for data collection, but the involuntary nature of neural signals complicates traditional consent models.[28]

The classification of neural data within existing legal categories remains unclear, with questions about whether brain signals constitute medical information, biometric data, or an entirely new category requiring specialised protection.[29] Variations in privacy law across jurisdictions and regional human rights mechanisms create additional complications for neurotechnology deployment and data transfers between entities.[30]

The unique characteristics of neural data may necessitate development of existing legal frameworks that address mental privacy as a fundamental human right. Legislation must continue to balance the promotion of beneficial neurotechnology developments and the treatment of diseases with the robust protection of cognitive liberty and mental autonomy required to safeguard all of a person's interconnected and interdependent human rights. Furthermore, regulatory approaches must consider the dual-use nature of many neurotechnologies, which can serve both beneficial and potentially harmful purposes depending on their application. International cooperation and standardisation efforts will continue to prove essential to prevent regulatory arbitrage and ensure consistent protection of human rights across jurisdictions with respect to the use of neurotechnologies.[31]

FURTHER PRIVACY/ETHICAL CONSIDERATIONS

Human Dignity and Personal Autonomy

The deployment of neurotechnologies raises fundamental questions as regards human dignity and the boundaries of individual personhood. The potential for external control or influence over mental processes challenges core concepts of individual autonomy and self-determination that underpin democratic societies and human rights. Debates as to the nature of consciousness, free will, and personal identity become ever more relevant as neurotechnologies gain the ability to monitor and potentially influence these fundamental aspects of human experience.[32] Moreover, medical procedures that alter normal cognitive variation through neurotechnology interventions raises questions about neurodiversity and the social construction of personhood and identity.[33]

The development and deployment of neurotechnologies must also address questions of distributive justice and equitable access to cognitive enhancement capabilities. If neurotechnologies provide significant advantages in cognitive performance, their unequal distribution could exacerbate existing social inequalities and create new forms of cognitive stratification. The potential for neurotechnologies to be used for social control or discrimination against individuals raises concerns as regards acceptance of neurodiversity and the rights of individuals who may choose not to adopt enhancement technologies.

FREEDOM OF RELIGION OR BELIEF AND NEUROTECHNOLOGIES

The intersection of neurotechnologies with the enjoyment of the right to freedom of religion or belief presents novel, exceptional challenges. As brain-computer interfaces (BCIs), neural implants, and cognitive enhancement technologies advance rapidly, they raise profound questions about the sanctity of mental privacy, spiritual autonomy, and the protection of religious beliefs and practices. Freedom of thought, conscience and religion, enshrined in Article 18 of the Universal Declaration of Human Rights[34] and protected under other international covenants, encompasses both the internal forum of belief and the external manifestation of faith.[35] Neurotechnologies, by their very nature of interfacing with the human brain, potentially intrude upon the most intimate sphere of human experience – consciousness itself.

This convergence demands urgent attention in an era where technological capabilities continue in many spheres to outpace ethical considerations and, indeed, effective responses through the application of regulatory frameworks. The risks are particularly high given that religious freedom serves as both an individual liberty and a cornerstone of pluralistic democratic societies.[36] Understanding how neurotechnology developments might enhance, threaten, or fundamentally alter beliefs or religious experience is crucial for rights holders, policymakers, scientists, technologists, faith-based and religious communities alike.

RELEVANT CLINICAL AND CONSUMER APPLICATIONS OF NEUROTECHNOLOGIES

Consumer Applications

Consumer markets increasingly offer neurotechnologies-based devices and applications for practices including meditation, guided engagement in spiritual experiences, and the exploration of consciousness.[37] Certain brain stimulation devices are currently marketed for 'transcendental experiences' intend to induce altered states of consciousness traditionally achieved through practices such as prayer, meditation, or ritual.[38] Virtual and augmented reality systems aim to create immersive religious experiences, potentially substituting for, or supplementing, traditional modes of worship. Certain neurofeedback devices already available to consumers claim to facilitate deeper spiritual connection and enhanced contemplative practices.[39]

Clinical Applications

Clinical neurotechnologies applications can intersect with concerns relating to the enjoyment of the right to freedom of religion or belief with regard to psychiatric and neurological treatments.[40] Deep brain stimulation for depression may alter personality traits, convictions and inclinations vis-à-vis beliefs. Neurotechnology-based therapies and treatments, increasingly available in clinical settings in certain jurisdictions, directly engage with consciousness in a manner that may overlap with spiritual and religious experiences. The use of neural prostheses and brain-computer interfaces (BCIs) raise questions with respect to the integrity of human consciousness. In addition, technologies may pose challenges to concepts of moral responsibilities that feature in many beliefs and religious traditions.

BENEFITS AND OPPORTUNITIES

Neurotechnologies could offer significant potential cognitive benefits for individuals for whom religious practice and spiritual wellbeing plays an important part in their life. For individuals with neurological conditions that may impair their ability to engage in traditional religious observances, neurotechnologies might restore cognitive functions that better enable access and engagement to spiritual practices. For example, neurotechnologies such as brain-computer interfaces (BCIs) and other assistive devices could enable individuals with neurodegenerative diseases that impair mobility to more actively participate in collective religious practices and attend places of worship in their communities.[41] Neurofeedback systems might genuinely enhance meditative practices and spiritual development, complementing rather than replacing traditional methods.

Research on applications of neurotechnologies could deepen understanding of religious experience, potentially validating the neurological basis of spiritual phenomena and contributing to greater understanding and interfaith dialogue.[42] For religious and faith-based communities, these technologies could offer new tools for pastoral care, particularly in addressing an array of mental health challenges that intersect with spiritual wellbeing.[43] The therapeutic benefits of clinical neurotechnologies could potentially align with convictions and values of healing, restoration and preservation of human dignity.

Risks and Challenges

Risks to the enjoyment of the right to freedom of religion or belief from the advance of neurotechnologies are multifaceted and profound. Direct manipulation of neural activity raises concerns about the authenticity and voluntariness of the experience of religion and faith. Where spiritual states may be induced through a technological intervention, questions can arise as to the genuineness and how events are actually experienced, essentially raising question as to their substance, validity and rationality.[44] Absent safeguards, the commercialisation of spiritual and religious experiences through neurotechnologies-based interventions may commodify aspects of phenomena connected to religion or belief that potentially undermine their spiritual significance.

Privacy concerns are certainly paramount, as neurotechnologies capable of collecting and processing neural data could potentially access thoughts pertaining to religion, beliefs, and experiences. Such capabilities raise spectres of religious persecution or discrimination based on the misuse of neural data.[45] Furthermore, the involuntary use of neurotechnologies, whether applied through coercion or as conditions of employment or social participation, could constitute violations of freedom of conscience.

Additionally, cultural and theological challenges may emerge where neurotechnological interventions alter personality, memory, or consciousness in ways that conflict with religious anthropologies. Faith traditions such as specific beliefs, practices, and rituals that reflect convictions, consciousness, and human dignity may be challenged by how certain neurotechnological applications function and influence cognition.[46]

THE RIGHTS OF PERSONS WITH DISABILITIES: IMPACT OF NEUROTECHNOLOGY DEVELOPMENTS

The rapid advancement of neurotechnologies represents one of the most significant developments in modern medical science, offering unprecedented opportunities to address neurological disabilities while simultaneously raising complex ethical, social, and practical concerns. Neurotechnologies encompass a broad spectrum of interventions, from brain-computer interfaces (BCIs) and deep brain stimulation to neural prosthetics, all designed to interact with the human nervous system.[47]

For the global community of persons with disabilities—estimated at over one billion individuals worldwide;[48] these technologies may present a paradigmatic shift in how we conceptualize disability, treatment, and human enhancement. The promise of restored mobility, improved communication capabilities and cognitive enhancement for individuals represents transformative potential that could fundamentally alter their lived experiences. However, the development and implementation of neurotechnologies occur within a complex landscape of competing interests, values, and priorities.[49] While these technologies offer remarkable therapeutic possibilities, they also introduce novel risks including surgical complications, long-term safety concerns, questions of autonomy and identity, and potential exacerbation of existing social inequalities.[50] Furthermore, the intersection of neurotechnology with disability raises profound questions about the social model of disability, the ethics of enhancement versus treatment, and the risk of technological solutions overshadowing necessary social and environmental accommodations.[51]

This analysis examines the current state of neurotechnologies development, evaluates both the transformative benefits and significant risks these technologies present for persons with disabilities, and addresses the critical questions that must guide responsible innovation and implementation in this rapidly evolving field.

CLINICAL TREATMENTS FOR REDUCED MOBILITY

Brain-Computer Interfaces and Neural Prosthetics

Brain-Computer Interfaces (BCIs) research have achieved notable successes recently in translating neural signals into actionable outputs, enabling individuals with paralysis to control computer cursors, robotic arms, and communication devices.[52] Studies have demonstrated successful implementations of both invasive and non-invasive BCIs, with recent trials showing individuals with tetraplegia achieving typing speeds comparable to smartphone users and controlling prosthetic limbs with remarkable dexterity.[53] The integration of artificial intelligence and machine learning algorithms has significantly improved the accuracy and responsiveness of these systems, while miniaturization has made implantable devices more practical for long-term use.[54]

Therapeutic Neurostimulation Technologies

Deep brain stimulation (DBS) has expanded beyond initial applications for diseases such as Parkinson's to treat a broader range of conditions including essential tremor, dystonia, epilepsy, and emerging applications for depression and obsessive-compulsive disorder (OCD).[55] Transcranial stimulation techniques offer non-invasive alternatives for treating various neurological and psychiatric conditions, with growing evidence for applications in stroke rehabilitation and depression treatment.[56]

Motor Function Restoration and Mobility Enhancement

Age-related motor decline, including conditions such as Parkinson's disease, essential tremor, and general frailty, represents another major application area of neurotechnologies. Brain-computer interfaces (BCIs) are being adapted to control assistive devices, robotic exoskeletons, and smart home environments, potentially enabling persons with motor impairments to maintain independence and quality of life.[57]

Neurotechnologies have shown promise in addressing chronic pain conditions common in elderly populations, while also potentially improving mobility through targeted neural pathway activation.[58] Functional electrical stimulation (FES) systems are being refined to provide more natural movement patterns and reduce the risk of falls through improved balance and coordination.[59]

BENEFITS FOR PERSONS WITH DISABILITIES: REALISING THE HUMAN RIGHT TO HEALTH

Restoration of Impaired Functions

Neurotechnologies offer direct pathways to restore lost or impaired functions. For individuals with spinal cord injuries, BCIs can bypass damaged motor pathways to restore communication between the brain and paralyzed limbs and empowering patients.[60] Research in motor restoration now extends beyond only limb control to include restoration of speech for individuals with conditions like ALS or stroke-related aphasia, where neurotechnologies are being developed to interpret neural signals and convert them to synthesised voice outputs.[61] These technologies may provide not just functional restoration but also psychological benefits through a renewed sense of agency, autonomy and independence.[62]

Enhancement of Existing Mental and Physical Capabilities

Beyond restoration, neurotechnologies may be used to enhance residual capabilities in individuals with partial disabilities. Sensory substitution devices can provide alternative sensory inputs for individuals with visual or auditory impairments,[63] while cognitive enhancement neurotechnologies show promise for certain individuals with memory impairments or executive function disorders.[64]

Improved Quality of Life and Social Participation

The functional improvements enabled by neurotechnologies translate directly into enhanced quality of life through increased independence, expanded employment opportunities, and greater social participation.[65] The ability to communicate, control one's interactions with the surrounding environment and engage in previously inaccessible activities can improve psychological well-being whilst also potentially reducing caregiver burden and healthcare needs.[66] These technologies may also offer the potential for an individual's more seamless integration into digital environments, potentially reducing certain barriers to participation in an increasingly connected world.[67]

HUMAN RIGHTS RISKS AND CHALLENGES

Safety and Medical Risks

Invasive neurotechnologies (such as BCIs) carry inherent surgical risks including infection, bleeding, and device malfunction.[68] Long-term safety data remains limited; concerns regarding chronic immune responses, tissue damage, and device degradation over time all remain significant.[69] The complexity of the nervous system means that interventions may have unintended consequences that may potentially only manifest many years after neurotechnologies are implemented as therapeutic interventions.[70]

Either software or hardware failures in critical life-supporting neurotechnologies could potentially have serious medical consequences, while the need for periodic surgical revisions may expose patients to repeated risks.[71] The challenge of balancing the desire to encourage innovation while meeting safety and ethical concerns constitutes an ongoing tension in research.[72]

Ethical and Privacy Concerns

Neurotechnologies raise fundamental questions with regard to notions of personal identity, autonomy, and what constitutes the "self." Persons using neurotechnologies may question whether their enhanced capabilities represent their own abilities or are otherwise technological artifacts. The potential for external control of neural devices raises concerns relating to personal autonomy, particularly regarding data privacy, device modification, and the possibility of remote manipulation.[73]

Societal and Cultural Implications

The emphasis on technological solutions to disability may inadvertently reinforce perspectives that view disability primarily as individual pathology requiring fixing, potentially undermining social model approaches that emphasise environmental and attitudinal barriers.[74] This technological focus might possibly reduce investment in universal design, accessibility improvements, and social inclusion initiatives. Neurotechnologies may contribute to the stigmatisation of individuals who choose not to use available technologies or for whom these technologies are ineffective, creating pressure for technological adoption and marginalising those who rely on other accommodations, assistive technologies or treatments.

In addition, the financial costs of neurotechnologies risk creating or exacerbating existing inequalities in healthcare access, potentially creating a two-tier system where advanced treatments are available only to the wealthy. This economic barrier could paradoxically increase rather than decrease disability-related disadvantages.[75]

HUMAN RIGHTS IMPLICATIONS FOR OLDER PERSONS OF NEUROTECHNOLOGIES

The intersection of neurotechnology and geriatric medicine represents one of the most promising yet ethically complex frontiers in contemporary healthcare innovation. As global populations age rapidly, with the World Health Organization projecting that the number of people aged 60 and above will increase from 1 billion in 2020 to 2.1 billion by 2050, the burden of age-related neurological conditions continues to escalate.[76]

CURRENT NEUROTECHNOLOGY DEVELOPMENTS RELEVANT TO OLDER PERSONS

Cognitive Enhancement and Dementia Intervention Technologies

The development of neurotechnologies specifically targeting cognitive decline represents a rapidly evolving field with particular relevance to elderly populations. Transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation (TMS) have emerged as leading non-invasive approaches for addressing mild cognitive impairment and early-stage dementia. These technologies work by modulating neural activity in specific brain regions associated with memory formation, executive function, and attention processing.[77] Deep brain stimulation (DBS) applications have expanded beyond movement disorders to include experimental treatments for treatment-resistant depression and cognitive enhancement in neurodegenerative conditions.[78]

Sensory Restoration Technologies

Sensory impairments significantly impact quality of life in elderly populations, and neurotechnology offers innovative approaches to address these challenges.[79] Advanced cochlear implants and auditory brainstem implants are already being optimized for older persons while considering age-related changes in neural plasticity and auditory processing.[80] Retinal implants represent another emerging technology that may benefit older persons with age-related macular degeneration and other vision-limiting conditions.[81]

BENEFITS OF NEUROTECHNOLOGY FOR OLDER PERSONS

Enhanced Quality of Life and Functional Independence

The primary benefit of neurotechnology applications for older persons lies in their potential to preserve or restore functional independence across multiple domains. Cognitive enhancement technologies may help elderly individuals maintain mental acuity longer, potentially delaying the need for intensive care interventions and preserving personal autonomy.[82] Motor restoration can enable continued participation in meaningful activities and reduce dependence on caregivers.

Neurotechnology therapeutics can also offer the potential for personalised interventions tailored to individual ageing trajectories and specific impairment patterns.[83] Emerging neurotechnologies can now be adjusted in real-time based on patient response and changing needs, providing a level of customization particularly valuable in the heterogeneous elderly population.[84]

Economic and Healthcare System Benefits

From a broader perspective, effective neurotechnology interventions for elderly persons could significantly reduce healthcare costs by delaying institutionalization, reducing hospitalization rates, and minimizing the need for intensive caregiving services.[85] The economic burden of age-related neurological conditions is substantial, and technologies that can extend healthy aging or slow disease progression represent important cost-effectiveness considerations for healthcare systems worldwide.[86]

Social and Psychological Benefits

Neurotechnologies may also provide significant social and psychological benefits by enabling elderly persons to maintain social connections, continue engaging in meaningful activities, and preserve their sense of identity and purpose.[87] Treatments that enhance communication abilities, support memory function, or improve mobility can have profound impacts on social isolation and depression, which are significant concerns in elderly populations.[88]

RISKS AND ETHICAL CONSIDERATIONS

Safety and Physiological Risks

The use of neurotechnologies in elderly populations raises unique safety concerns related to age-related changes in brain function. Elderly individuals may be more susceptible to adverse effects from neural stimulation due to altered blood-brain barrier function, increased cerebrovascular fragility, and reduced neural plasticity.[89] The risk-benefit profile of invasive procedures requires careful evaluation considering shorter life expectancy and higher surgical risks.[90]

Cognitive and Psychological Risks

The potential for neurotechnologies to alter personality, decision-making capacity, or sense of self in older persons constitutes a genuine human rights risk. Concerns arise as to whether cognitive enhancement technologies might create unrealistic expectations or interfere with natural ageing processes.[91] The possible psychological impact of becoming dependent on devices for basic cognitive or motor functions also requires careful consideration.

Ethical and Social Justice Concerns

The use of neurotechnologies for treatments raises fundamental questions about distributive justice, accessibility, and the potential for creating or exacerbating health disparities. High costs associated with many neurotechnologies may limit access to wealthy individuals or well-funded healthcare systems, potentially creating new forms of inequality in ageing experiences.[92]

Coercion on older persons to accept technological interventions, particularly in institutional settings where the benefits may accrue primarily to caregivers or healthcare systems rather than the individuals themselves, are also of concern. Ensuring informed consent becomes more complex when dealing with individuals who may have cognitive impairments or who may not fully understand the long-term implications of neurotechnology interventions.[93]

REGULATORY CHALLENGES: OVERSIGHT AND ENFORCEMENT

Regulatory Framework Development
Current legislative and regulatory frameworks applying to neurotechnologies may not adequately address the unique considerations relevant to older patients. Age-specific clinical trial requirements, safety monitoring protocols, and efficacy standards need development to ensure appropriate oversight of neurotechnology applications in older persons' treatment using neurotechnologies.[94]

Healthcare Integration and Training
The successful implementation of neurotechnology for elderly persons may require significant changes in healthcare delivery models, including specialized training for clinicians, neurologists, and other healthcare providers. Integration of neurotechnologies with existing care coordination systems and consideration of caregiver needs and capabilities will prove essential in deployment.[95]

NEUROTECHNOLOGIES IN THE JUSTICE SYSTEM: DEVELOPMENTS, BENEFITS, AND RISKS IN CIVIL AND CRIMINAL PROCEDURE

CIVIL PROCEDURE

As brain-computer interfaces (BCIs), neural imaging and other cognitive monitoring capabilities continue to evolve rapidly from experimental to practical applications, they present novel challenges to traditional legal frameworks governing evidence, testimony, and procedural rights. The analysis commences with a brief overview of the scientific and historical development of the application of different kinds of neuroscientific evidence in civil procedure and discusses the inherent challenges arising from the interpretation and utilisation of such evidence in court proceedings.

Relevant neurotechnologies in this context comprise a rapidly expanding array of tools and techniques for measuring, interpreting, and potentially modifying brain activity, including functional magnetic resonance imaging (fMRI), electroencephalography (EEG), transcranial stimulation, brain-computer interfaces, and emerging neurochemical detection methods.[96] These technologies promise unprecedented insights into human cognition, memory, decision-making, and emotional states—all fundamental elements of legal proceedings.[97] The justice system's growing interest in neurotechnologies stems from their potential to address longstanding challenges in both criminal and civil procedure: determining truthfulness, assessing mental capacity, understanding intent, evaluating competency, and measuring damages related to neurological harm.[98] However, the integration of these technologies into legal frameworks raises profound questions about privacy, reliability, constitutional protections, and the very nature of human agency and responsibility.[99]

Currently, in certain jurisdictions, neurotechnology applications are indeed being applied in justice systems, underscoring their transformative potential, albeit with significant possible risks and limitations with respect to scalability. While neurotechnologies offer valuable tools for enhancing accuracy and fairness in legal proceedings, their implementation requires careful consideration of scientific validity, ethical implications, and constitutional safeguards to prevent misuse and preserve fundamental rights.

CURRENT NEUROTECHNOLOGY DEVELOPMENTS IN LEGAL CONTEXTS

Use of Brain Imaging Technologies in Legal Proceedings

Functional neuroimaging has emerged as the most prominent neurotechnology in legal settings.[100] fMRI studies of brain activation patterns during deception have generated considerable interest as potential 'lie detection' tools, with several enterprises developing commercial applications.[101] Structural MRI scans increasingly serve as evidence in criminal sentencing, particularly in cases involving traumatic brain injury or developmental abnormalities that might explain criminal behaviour.[102] Positron emission tomography (PET) scans and other imaging modalities are being introduced to demonstrate neurological damage in personal injury litigation and to assess competency in various legal proceedings.[103]

Electrophysiological Monitoring

EEG-based technologies, including event-related potentials and so-called 'brain fingerprinting' techniques, are being explored for memory detection and truthfulness assessment. These approaches measure electrical brain activity in response to stimuli, potentially revealing whether individuals possess specific knowledge about events or locations.[104] Some jurisdictions have begun accepting EEG evidence in limited circumstances, though admissibility standards vary significantly.[105]

Cognitive Enhancement and Modification Technologies

Emerging neurotechnologies extend beyond measurement to potential cognitive modification. Transcranial stimulation techniques can temporarily alter brain function, raising questions about their use in rehabilitation, competency restoration, and broader ethical and human rights considerations around treatments using cognitive enhancement on individuals.[106] Deep brain stimulation and other therapeutic interventions present further complex questions as regards agency and responsibility in respect of the broader implications for the rights of others within communities. Delivery of these capabilities may further widen disparities in terms of access to justice, including remedies. In addition, concerns may also arise in connection with neurotechnologies' delivery widening social inequities, bias and discrimination.[107]

BENEFITS AND APPLICATIONS IN CRIMINAL PROCEDURE

Enhanced Accuracy in Determinations of Truthfulness

Certain capabilities under development in the sphere of neurotechnologies potentially offer improvements over traditional polygraph testing, which has limited admissibility in legal proceedings due to ongoing concerns as to its reliability.[108] Neurotechnologies-based lie detection methods claim to measure deception more directly by examining neural correlates of truthfulness rather than peripheral physiological responses.[109] These technologies might provide more objective assessments of witness credibility and defendant statements, potentially reducing wrongful convictions based on false confessions or perjured testimony.

Mental State and Competency Assessment

Developments in neuroimaging have allowed for the provision of valuable insights into the mental states of defendants in proceedings, their cognitive capacity, and neurological conditions that affect an accountability with regard to individual criminal responsibility.[110] These technologies can enhance competency evaluations, determinations of sanity and mental faculties, and assessments of mitigating factors in sentencing.[111] Brain scans may reveal previously undetected neurological conditions that could potentially reflect physiological and cognitive changes that may assist assessments of criminal behaviour, possibly supporting more appropriate therapeutic interventions rather than purely punitive measures.

Rehabilitation and Recidivism Prevention

Developments in the capacities of neurotechnologies may eventually enable more precise understanding of cognitive deficits and neurological factors contributing to criminal behaviour.[112] This knowledge could potentially inform more targeted rehabilitation programs and treatments, medication management, and therapeutic interventions designed to address underlying neurological causes of problematic conduct. Brain-based assessments might also improve risk evaluation and parole decisions by providing objective measures of rehabilitation progress.[113]

BENEFITS AND APPLICATIONS IN CIVIL PROCEDURE

Personal Injury and Medical Malpractice Litigation

Current neuroimaging technologies provide objective evidence of brain injury, cognitive impairment, and neurological damage in tort cases. These technologies can thus be used to demonstrate the extent of harm, support damage calculations, and distinguish between pre-existing conditions and injury-related changes.[114] Advanced imaging techniques may detect subtle brain injuries previously difficult to document prior to advances in neuroimaging, thus allowing for more nuanced analysis of changes in physiological conditions in the process of assessing possible neurological harm caused to an individual.[115]

Capacity and Competency Determinations

Civil proceedings often require assessments of mental capacity in respect of deliberations concerning processes such as contracts, wills, guardianship, and other legal decisions. Neurotechnologies that allow for more objective measures and assessment of cognitive functions could potentially assist in the resolution of disputes over mental capacity, and provide clearer guidance for courts determinations in cases of protective arrangements, for example.[116] Such assessments that leverage neurotechnology-based insights could be particularly valuable in cases involving dementia, developmental disabilities, or other cognitive impairments.[117]

Employment and Workplace Discrimination Law

Neuroimaging evidence may support claims related to workplace discrimination based on neurological conditions or demonstrate the cognitive effects of occupational exposures.[118] These technologies can provide objective documentation of neurological impairments that affect employment capacity and support reasonable accommodation requests under disability laws.[119]

RISKS AND CHALLENGES

Scientific Reliability and Validity Concerns

Current neurotechnologies face significant limitations in reliability, accuracy, and interpretation. Brain imaging studies often involve small sample sizes, variable methodologies, and uncertain clinical significance. The translation from group-level research findings to individual legal determinations presents substantial challenges.[120] Many neurotechnologies lack sufficient validation for forensic applications, raising concerns about premature adoption in high-stakes legal contexts.[121]

Privacy and Data Protection

Neurotechnology applications engage fundamental concerns pertaining to the rights to privacy and data protection rights.[122] In addition, due process considerations arise, including privilege against self-incrimination and protections against unreasonable searches, in the context of invasive examinations of neural data derived from the individual.[123] Furthermore, courts may need to determine in their evaluations as to whether neurotechnologies-based evidence neural data collection and processing constitutes testimonial evidence or physical evidence, affecting admissibility and procedural protections.[124] The invasive nature of certain neurotechnologies also raises additional questions as regards prior and informed consent, particularly for incarcerated individuals in detention facilities or those with diminished capacity.[125]

BROADER SOCIAL JUSTICE IMPLICATIONS: BIAS AND DISCRIMINATION

Neurotechnologies may perpetuate or exacerbate existing biases in the justice system. Brain imaging studies have historically underrepresented diverse populations, leading to serious oversights in respect of the representativeness of ethnic minorities and other vulnerable groups, such as persons with disabilities, in datasets: potentially leading to discriminatory application.[126] Cultural, socioeconomic, and individual differences may thus be cited as factors influencing brain structure, function or cognitive ability.[127] Such misinterpretations could lead to parties propagating narratives that these factors influence pathological or criminal predispositions.[128] Furthermore, the cost of accessing certain neurotechnologies could create disparities in access to potentially exonerating or mitigating evidence.[129]

ETHICAL AND LEGAL FRAMEWORK CONSIDERATIONS

Admissibility Standards and Expert Testimony

Courts should develop appropriate standards for evaluating neurotechnologies-based evidence, building upon existing frameworks such as the Daubert and Frye standards.[130] Expert testimony requirements will become ever more crucial given the complex, evolving nature of neuroscience and neurotechnologies research and development. In addition, legal professionals will likely need further training with regard to developing enhanced scientific literacy to effectively evaluate and present evidence linked to the exploitation of neurotechnologies.[131]

Prior and Informed Consent and Procedural Protections

The implementation of neurotechnologies requires robust informed consent procedures, particularly given the complexity of the underlying science and potential implications for legal proceedings.[132] Special protections may be necessary for vulnerable groups, including children, persons with disabilities, and persons being held in custody, including pre-trial detention.

Regulation and Professional Standards

Professional organizations and regulatory bodies engaged within the justice system will need to develop extensive guidelines for the forensic application of neurotechnologies. These standards shall require advancing knowledge and the education of advocates and address practitioner qualifications, equipment specifications, data interpretation protocols, and ethical boundaries for the exploitation of neurotechnologies in the justice system.[133]

FUTURE IMPLICATIONS FOR CIVIL LAW

Neurotechnologies represent both tremendous opportunities and significant risk for justice systems worldwide. Their potential to enhance accuracy, fairness, and understanding in legal proceedings is substantial, offering tools to address longstanding challenges in truth determination, capacity assessment, and rehabilitation. However, the current state of neuroscience and neurotechnologies research, combined with continued concerns over human rights, transparency, accountability and reliability, thus demands a cautious and thoughtful implementation of any neurotechnologies-based innovation. The rapid pace of neurotechnology development promises continued evolution of applications in law. In particular, the integration of artificial intelligence (AI) with evolving brain imaging capabilities may enhance diagnostic accuracy.[134] Portable, real-time monitoring devices could enable continuous assessment of mental states and cognitive function.[135] However, such advances in technical capabilities may in the future also raise novel questions as regards surveillance, autonomy, and the appropriate limits of the use of neurotechnologies beyond legal proceedings for the rule of law in democratic societies.

The integration of neurotechnologies into legal frameworks requires interdisciplinary collaboration among neuroscientists, legal scholars, ethicists, and practitioners. Robust validation studies, clear admissibility standards, and comprehensive procedural protections are essential prerequisites for responsible adoption. The ultimate goal must be enhancing justice while preserving fundamental rights and human dignity. As neurotechnologies continue to evolve, the legal system must maintain a delicate balance between embracing beneficial innovations and protecting against premature or inappropriate applications. Success in this endeavour will require ongoing dialogue, careful empirical evaluation, and unwavering commitment to both scientific rigour and human rights standards. The future use of neurotechnologies in the justice system depends on our collective ability to harness powerful innovations in this domain while safeguarding.

CONCLUSIONS

The emergence of neurotechnologies marks a pivotal moment in human history, comparable to other transformative innovations that have reshaped society and human experience. The development of neurotechnologies represents both an unprecedented opportunity for human advancement and a fundamental challenge to traditional concepts of privacy and cognitive liberty. The benefits of these technologies—from treating intractable medical conditions to enhancing human capabilities—are potentially substantial, as has already been evidenced by early medical applications of neurotechnologies in treatments of disorders such as Parkinson's Disease.[136] However, the risks they pose to mental privacy and individual autonomy are equally significant and require careful consideration and proactive governance and regulation.

The path forward requires a delicate balance between promoting beneficial innovation and protecting fundamental human rights. This balance can only be achieved through interdisciplinary collaboration amongst all concerned stakeholders: governments, technologists and neuroengineers, bioethicists, legal scholars, and civil society. The further development of appropriate frameworks must occur in parallel with technological advancement, rather than as an afterthought to innovation.

'INFORMED CONSENT' AS A BASIS FOR DATA PROCESSING: FURTHER LEGAL BASES

Informed consent, while fundamental to data protection law, is but one of the legal bases for data processing in many jurisdictions. What constitutes meaningful informed prior consent for neurotechnologies interventions that may access involuntary mental processes? Furthermore, meaningful informed consent may prove complex to discern where technologies fundamentally alter cognitive or other physiological capabilities. In addition, also at issue is how decisions can be made regarding neurotechnological interventions for individuals with cognitive disabilities who may lack capacity for informed consent. Traditional consent models may prove inadequate for neurotechnologies that can extract neural data for development of inferences without conscious awareness or control of the individual. Relying solely on consent is inappropriate, given that data processing activities in the context of the use of neurotechnologies may be lawfully permitted under other provisions.[137] For example, healthcare providers may be required to maintain medical records to meet regulatory requirements, or a patient may be unable to provide consent given their medical condition: in this case, a third party, such as a clinician, may make a decision in the best interests of the data subject (the patient). Vital interests justify processing when someone's life is at stake, such as medical emergencies where unconscious patients cannot provide consent. These concerns all underscore the need for safeguards, which prove necessary to protect user autonomy and prevent coercion or undue influence in treatment decisions involving neurotechnologies.

RESOLVING SPECIFIC HUMAN RIGHTS CONCERNS RELATING TO DISABILITIES

Neurotechnologies represent both tremendous opportunities and significant challenges for persons with disabilities. The potential for restored function, enhanced health, and improved quality of life is unprecedented. However, the realisation of this great potential requires careful attention to human rights, medical safety, equity, autonomy, and broader social implications.

The path forward requires inclusive development processes for neurotechnologies that centre the voices and experiences of persons with disabilities, robust regulatory frameworks that balance innovation with protection, and sustained commitment to ensuring equitable access to therapies. Critically, neurotechnology advancement must occur alongside continued investment in social inclusion, environmental accessibility, and the full spectrum of supports that enable participation and dignity for all persons with disabilities.

The questions raised by the advancement of neurotechnologies development are not merely technical or medical but also fundamentally human rights-based, social and ethical. Development of neurotechnologies will determine whether they become tools of empowerment that assist the realisation of the right to health or are otherwise instruments that inadvertently reinforce existing inequalities and limitations. Ultimately, success will be measured not just by technological sophistication, but rather by the extent to which innovations contribute to a more inclusive and equitable society for all persons with disabilities.

The future of neurotechnologies and disability lies not in choosing between either technological or social approaches, but in meaningfully integrating both to create an environment where all individuals can participate fully in society, whether through medical intervention or technological enhancement, environmental modification, social support, or—most likely—some combination of all these approaches tailored to individual needs and preferences.

OLDER PERSONS, SHIFTING DEMOGRAPHICS AND INTERGENERATIONAL EQUITY

The development and application of neurotechnology for elderly populations represents a complex intersection of technological innovation, clinical need, and ethical consideration. While these technologies offer significant potential benefits including enhanced quality of life, preserved independence, and improved management of age-related neurological conditions, they also present substantial risks and challenges that must be carefully addressed.

The unique characteristics of elderly populations, including increased vulnerability, altered physiology, and complex social circumstances, necessitate specialized approaches to neurotechnologies development and implementation. Current research gaps include limited age-specific clinical trial data, inadequate understanding of long-term outcomes, and insufficient attention to human rights, ethical and social justice considerations. Successful integration of neurotechnologies into healthcare will require interdisciplinary collaboration amongst clinicians, ethicists, policymakers, and older persons themselves. Priority should be given to developing age-appropriate safety protocols, establishing ethical frameworks for implementation, ensuring equitable access, and conducting rigorous long-term outcome studies.

The potential societal benefits of effectively harnessing neurotechnology for healthy ageing are substantial, including improved quality of life for millions of older persons, reduced healthcare costs and enhanced social and economic participation. However, realising these benefits will require careful attention to the risks and challenges identified in this analysis, as well as continued investment in research. A key objective must be to develop and implement neurotechnologies that enhance rather than replace human capabilities, preserve dignity and autonomy, and contribute to a vision of aging that emphasizes continued growth, contribution, and well-being throughout the human lifespan. This will require not only technological innovation but also social innovation in how we conceptualize and support an ageing global population.

RECOMMENDATIONS

1. Neurotechnologies advancement for clinical use should be guided by a human rights-based approach to health

The human rights-based approach (HRBA) to health provides a framework for development and policy in relation to neurotechnologies that puts people's human rights at its core, shifting focus from needs to entitlements by empowering rights-holders (individuals) to claim their rights and strengthening duty-bearers (governments, institutions, healthcare systems) to fulfill their obligations. Key principles such as participation, accountability, non-discrimination, transparency, and empowerment, must ensure development of neurotechnology addresses root causes of inequality and marginalization in access to healthcare.[138]

2. Support research on the integration of neurotechnologies within healthcare systems

Despite growing interest in neurotechnological interventions for disability support, significant knowledge gaps remain regarding their effective incorporation into established healthcare infrastructures. Critical questions persist concerning the systematic integration of neurotechnologies within existing clinical and community-based service delivery models for persons with disabilities. The requisite competencies, educational frameworks, and ongoing professional development mechanisms necessary to prepare healthcare providers, disability service professionals, and informal caregivers for neurotechnology implementation remain inadequately defined.

Furthermore, the relationship between neurotechnological solutions and traditional approaches to accessibility, particularly social and environmental modifications, requires rigorous investigation to ensure complementary rather than competing intervention strategies. The absence of longitudinal research examining the complex interactions between neurotechnologies and established disability-related interventions represents a substantial gap in the evidence base, limiting informed decision-making about integrated care pathways.

Additionally, consensus on appropriate outcome measures and evaluation frameworks across diverse neurotechnological applications for disability remains elusive. Without standardized metrics for assessing efficacy, effectiveness, and broader impact across different neurotechnology modalities, comparing interventions and establishing best practices becomes problematic. Addressing these interconnected research priorities is essential for developing evidence-informed policies and practices that optimize neurotechnology deployment while safeguarding the rights, preferences, and wellbeing of persons with disabilities.

3. Build capacities to address health equity and access for older persons to neurotechnologies

The emergence of neurotechnological interventions for ageing populations presents significant concerns regarding equitable distribution and access across different cohorts and communities of older persons. Current research insufficiently addresses how socioeconomic stratification, cultural diversity, and geographic disparities may create differential access to neurotechnology-based healthcare solutions, potentially widening existing health inequities among older adults.

To date, broad evidence has emerged that innovation in medical technologies frequently exhibits inequitable adoption patterns, with economically disadvantaged, culturally marginalized, and geographically isolated populations experiencing delayed or limited access.[139] This disparity is likely to be replicated as neurotechnologies are adopted. In addition, targeted research examining the specific barriers and facilitators to neurotechnology accessibility for diverse elderly populations remains notably absent. The mechanisms through which cost structures, insurance coverage policies, healthcare infrastructure limitations, and cultural acceptability influence neurotechnology uptake among various elderly subgroups require systematic investigation.

Moreover, the intersection of multiple disadvantage factors, including rural residence, low socioeconomic status, racial and ethnic minority status, and limited health literacy, and their cumulative impact on access to neurotechnologies for clinical treatments remains poorly understood. Without evidence-based strategies to promote equitable distribution, neurotechnological advances risk becoming privilege-amplifying interventions that disproportionately benefit already-advantaged populations while leaving vulnerable elderly groups further behind.

There exists an urgent need for research that identifies effective policy frameworks, service delivery models, and implementation strategies capable of ensuring universal access to beneficial neurotechnologies regardless of socioeconomic position, cultural background, or geographic location. Such investigation must encompass affordability mechanisms, culturally responsive implementation approaches, infrastructure development for underserved areas, and community engagement strategies that center the needs and preferences of marginalized elderly populations. Proactive attention to equity considerations is essential to prevent neurotechnologies from inadvertently exacerbating the health disparities that already disproportionately affect vulnerable aging populations.

4. Develop robust scenario planning to model long term neurotechnologies impacts for society

Scenario planning constitutes an essential methodological approach for anticipating the multifaceted implications of neurotechnology implementation across consumer and clinical contexts. The inherent complexity and uncertainty surrounding neurotechnological development trajectories necessitate structured foresight mechanisms that transcend linear prediction models.

Within clinical environments, scenario planning will enable healthcare systems to better prepare for divergent regulatory pathways, reimbursement structures, and integration challenges that may emerge as neurotechnologies transition from experimental to standard care.[140] Multiple plausible scenarios, ranging from widespread adoption to severe regulatory restrictions, require distinct infrastructural investments, training of healthcare professionals and governance frameworks. Without systematic scenario analysis to discern future impacts, institutions risk misallocating resources or failing to establish necessary safeguards to human rights before critical concerns arise.

Consumer uses of neurotechnologies present equally complex eventualities requiring adoption of long term strategies. Neurotechnologies marketed directly to consumers may evolve along trajectories involving varying degrees of oversight and data commercialization. Scenario planning facilitates identification of potential tipping points where consumer neurotechnologies might blur the boundaries between therapeutic uses and enhancement, possibly creating novel privacy or data protection vulnerabilities or otherwise generating unexpected social stratifications.

Furthermore, the interdependencies between technological capabilities, regulatory responses, market forces, and public acceptance could create dynamic feedback loops that single-pathway forecasting cannot adequately capture. This development would heighten the risk of interferences with human rights. The capacity of scenario planning to explore multiple concurrent variables and their interactions can provide policymakers, clinicians, and industry stakeholders with robust frameworks for adaptive governance. This methodological approach could prove assistive in transforming uncertainty from a planning obstacle into a strategic asset, enabling proactive rather than reactive responses to neurotechnology's transformative potential.

5. Encourage research of the long-term effects of neurotechnology interventions on quality of life, functional independence, overall well-being and the enjoyment of human rights

The evaluation of neurotechnological interventions for different populations has to date predominantly emphasised short-term clinical efficacy metrics, leaving critical knowledge gaps regarding sustained impacts on wellbeing outcomes. Existing research inadequately addresses whether neurotechnology-mediated improvements persist over extended timeframes and, crucially, how such interventions influence broader constructs of quality of life, functional independence, holistic wellbeing and the progressive realisation of the right to health.[141]

Traditional clinical trial endpoint, typically focused on symptom reduction or neurophysiological parameter, frequently provide insufficient insight into outcomes most salient to individuals themselves and their tangible enjoyment of human rights. The absence of comprehensive longitudinal investigations examining patient-reported experiences, subjective wellbeing, social participation, autonomy preservation, and life satisfaction represents a substantial evidence deficit. Without such data, clinicians and policymakers cannot adequately assess whether neurotechnologies deliver meaningful improvements aligned with care priorities that emphasise human rights over mere biomedical indicators.[142]

Furthermore, the potential long-term consequences of neurotechnologies-based interventions in terms of implications for an individual's human rights, including impacts and adverse effects related to negative adaptation, dependency development, psychosocial implications, or delayed adverse events, remain poorly characterised across extended follow-up periods. In addition, the complex interplay between neurotechnology interventions and age-related trajectories of cognitive decline, physical frailty, and social engagement also requires sustained observation beyond typical clinical trial durations.

Therefore, there exists an urgent need for methodologically rigorous longitudinal studies that capture clinical efficacy alongside patient-centred metrics that adequately capture an holistic evaluation of neurotechnologies' sustained value propositions across interdependent human rights for different populations.

6. Address global disparities in neurotechnologies access, particularly given the concentration of research and development in more developed economies in the Global North

The geographically asymmetric distribution of neurotechnology research, development, and clinical implementation presents profound equity challenges that remain insufficiently addressed within current discourse. Existing neurotechnology innovation ecosystems exhibit marked concentration within high-income economies, creating substantial disparities in access that risk entrenching global health inequalities.[143] Moreover, evidence-based strategies for mitigating these geographical imbalances and promoting equitable neurotechnology diffusion across diverse economic contexts remain critically underdeveloped.[144]

The mechanisms through which resource-constrained healthcare systems in low- and middle-income countries (LMICs)[145] might feasibly adopt, adapt, and sustain neurotechnological interventions therefore requires systematic investigation. Current research provides limited guidance on contextually appropriate technology transfer frameworks that account for infrastructure limitations, healthcare workforce capacity constraints, and economic sustainability considerations specific to LMIC settings for neurotechnologies-based treatments. Furthermore, the applicability of neurotechnologies developed primarily within the clinical environments of developed economies to populations exhibiting different disease prevalence patterns, cultural contexts, and healthcare delivery models remains inadequately examined.[146]

In addition, capacity-building approaches that could enable local neurotechnology innovation, implementation, and maintenance within resource-limited settings currently lack empirical validation. Questions thus persist as regards the optimal models for knowledge transfer, technical training programmes, regulatory framework adaptation, and public-private partnerships capable of facilitating meaningful LMIC engagement beyond mere technology importation. Research to identify scalable, sustainable pathways toward neurotechnology democratisation must be encouraged so as to prevent these innovations from becoming exclusively accessible to privileged populations, thereby exacerbating rather than ameliorating global health disparities.

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