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Neurotechnology governance: the operational turn

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Neurotechnology governance is entering an operational turn, driven by the need to move beyond the articulation of ethical principles and to translate them into heterogeneous real-world settings through institutional capacity-building, regulatory fit, and coordination. This shift also concerns the conditions under which beneficial neurotechnology applications can emerge and scale responsibly.

A landscape in transition

Over the past 20 years, **neurotechnology** (see [Glossary](#)) has moved beyond clinical and research settings and increasingly interacts with consumer, workplace, educational, and **digital platform** environments. This *neurotechnology shift* [\[1\]ⁱ](#) is unfolding alongside an increasingly visible vocabulary of ethical principles and rights—including mental privacy, mental integrity, and autonomy [\[2\]](#)—as well as a growing range of normative initiatives across jurisdictions. These include global instruments such as UNESCO's Recommendation on the Ethics of Neurotechnology,ⁱⁱ constitutional amendments and bills in Chileⁱⁱⁱ and the USA,^{iv} national ethics guidelines in China,^v and Canada-based discussions [\[3\]](#).

Yet the central challenge confronting **neurotechnology governance** is no longer articulating high-level principles but increasingly determining how to govern neurotechnology across **heterogeneous settings**—for example, clinical environments, consumer markets, workplace applications, and digital platforms—characterized by differences in oversight pathways, institutional capacities, evidentiary standards, and incentive structures. Recent controversies illustrate this change of direction. In Chile, the *Girardi v. Emotiv* ruling—which brought public attention to the governance of **neurodata**^{i,vi} and consumer neurotechnology outside traditional medical contexts—is instructive. Rather than leveraging the new constitutional neurorights amendment, the Chilean Supreme Court reached its conclusions through existing privacy protection provisions [\[4\]](#)—shedding light on the lack of implementable mechanisms supporting the recently approved neurorights provision. More broadly, neurotechnology governance is now facing, in practice, a question familiar to other regulatory domains: how can broad normative commitments hold across uneven contexts of deployment?

Cross-sector discussions involving academic, legal, policy, and industry perspectives—including a growing number of multistakeholder convenings^{ii,vii,viii}—have made this question especially visible. These discussions point to an **operational turn** in neurotechnology governance ([Table 1](#)): a growing pressure to translate high-level principles into institutional, context-sensitive forms of implementation, coordination, and alignment. This reorientation is partial and uneven, yet it increasingly concerns not only risk mitigation but also the conditions under which beneficial neurotechnology applications can be developed, trusted, and scaled responsibly.

Glossary

Anticipatory governance: an approach that builds governance before a technology's effects are fully known, combining foresight, public engagement, and institutional flexibility so that oversight adjusts as evidence accumulates rather than only after harm occurs.

Biometric infrastructures: technical and institutional arrangements through which bodily and behavioral measurements are captured, stored, and linked for identification or inference. Neural signals can enter this category when they serve as identifiers or feed into systems built for other signals.

Calibration: adjusting the stringency of governance to the deployment setting, so that oversight tracks the actual distribution of benefits, risks, and institutional capacity, rather than applying uniform thresholds.

Digital phenotyping: the continuous collection of data from personal devices to characterize behavior and health, typically without dedicated measurement sessions.

Digital platforms: online environments that mediate between users and services while capturing interaction data and through which consumer neurotechnology and its outputs increasingly circulate.

Heterogeneous settings: deployment contexts that differ in oversight pathways, institutional capacity, evidentiary standards, and incentive structures such that a governance mechanism effective in one may fail in another.

Neuroabandonment: the withdrawal of support for an implanted neurodevice through company failure, discontinuation, or lack of maintenance, leaving users without the function that the device provided.

Neurodata: measurements of the structure, activity, or function of the nervous system obtained through neurotechnology, many of which correlate with mental states.^{vi}

Neurotechnology: tools that record, decode, or modulate nervous system activity, including brain-computer interfaces, neuroimaging techniques, and wearable or implantable neurodevices that are now moving from experimental and clinical settings toward real-world deployment.

Neurotechnology governance: the full set of arrangements that shape how neurotechnology is developed and used. Beyond binding regulation, these include soft-law instruments, professional standards, institutional procedures, funding conditions, procurement rules, and industry self-regulation, which differ in enforceability and in whom they bind.

Operational turn: a shift in emphasis from articulating what neurotechnology governance should protect to building institutional capacity, implementation tools, contextual calibration, and participatory mechanisms that make those commitments effective across the settings where neurotechnology is actually deployed.

Responsible research and innovation (RRI): a framework in which research and innovation are steered by anticipation of effects, reflection on

assumptions, inclusion of affected parties, and responsiveness to what these approaches reveal, rather than being assessed only after outputs reach the market and wider society.

Science and technology studies (STS): an interdisciplinary field that examines how scientific knowledge and technologies are shaped by social, institutional, and political processes, and how they, in turn, reshape those processes.

Uncertainty and governance pressure

Neurotechnology governance increasingly unfolds under conditions of uncertainty. This dynamic reflects a familiar version of the Collingridge dilemma [5]: governance

intervention is easiest when technological trajectories are still fluid, yet evidence about downstream harms, institutional dependencies, and large-scale social effects is often limited; by the time such effects become clearer, systems may already be entrenched. Recent calls for a moratorium on implantable nonmedical neurotechnology make this point sharply, warning that *ex post* litigation may arrive only after widespread exposure and potentially irreversible harm [6].

In neurotechnology, uncertainty does not lie only in what current systems can reliably

perform. It also concerns how quickly capabilities may scale, how they may converge with AI, digital platforms, and **biometric infrastructures**—including facial recognition, wearable physiological sensing, and **digital phenotyping**^{ix}—and how inferences drawn from these combined data streams may compound across institutional and social settings. This makes governance difficult to calibrate. The boundary between opportunity, possible risk, and legally actionable harm is often hard to draw, especially when the concern is confined not only to device malfunction but also to diffuse changes in

Table 1. A cartography of the operational turn in neurotechnology governance^a

Layer	Component	What it denotes
Structural diagnosis	Neurotechnology shift	Movement out of clinical and research settings into consumer, workplace, educational, and digital platform environments
	Normative proliferation	Rapid accumulation of principles, rights claims, and policy instruments across jurisdictions, from constitutional provisions to international recommendations
	Implementation pressure	The demand generated when normative commitments must be given effect in settings that differ in oversight pathways, institutional capacity, evidentiary standards, and incentives
Governance uncertainties	Intervention timing	Governance is most tractable before a technology settles into place, yet evidence of downstream harm typically arrives later
	Scaling dynamics	Uncertainty about how quickly capabilities grow and how far they extend once systems move beyond their original setting
	Risk–harm boundary	Difficulty distinguishing opportunity, potential risk, and legally actionable harm where effects are diffuse rather than device-level
	Uneven exposure	Risks and benefits are distributed unequally across settings and populations, so uniform thresholds fit poorly
Zones of governance pressure	Nonclinical deployment	Workplace, educational, and consumer markets, where oversight is fragmented, evidentiary standards unsettled, and consent structurally compromised
	Technological convergence	Integration with AI, digital platforms, and biometric infrastructures, which blurs regulatory boundaries and outpaces device-level oversight
	Institutional and jurisdictional coordination	Divergence in regulatory, industrial, and cultural traditions, making institutional speed and alignment governance variables in their own right
	Vulnerability and dependency	Concentration of exposure among people with disabilities, patients, and users reliant on continued device support, shaping access to benefits and continuity of care
Operational turn: core axes	From articulation to implementation	Shifting emphasis from what governance should protect to the institutional capacity, tools, and participatory mechanisms that make protection operable
	From uniform framing to calibration	Differentiating thresholds by context, so that clinical and assistive uses are not governed on the same terms as consumer and other nonclinical applications
	From restraint to enablement	Treating the conditions under which beneficial applications emerge, gain legitimacy, and scale responsibly as part of the governance task rather than external to it

^aThe table maps four analytical layers: what has changed, what remains uncertain, where governance pressure concentrates, and along which axes governance is reorienting. It is intended as an orienting map rather than a prescriptive framework.

mental states, behavior, or social environments. Debates on mental state inference from neurodata already illustrate this challenge. Epistemic harms such as self-doubt, epistemic insecurity, self-fulfilling prophecies, the sidelining of the subject, or the gradual atrophy of introspective capacities [7] show why governance of neurotechnology cannot rely only on clear, device-level harms (Box 1).

Under these conditions, uncertainty condenses into several zones of governance pressure. The first arises from the migration of neurotechnology into nonclinical domains, including workplace, education, and consumer markets. These settings often combine weak or fragmented oversight, uncertain evidentiary standards,^x and asymmetrical power or consent structures, including implicit coercion. As deployment scales, governance must differentiate between low-risk applications, high-benefit schemes, and domains requiring heightened scrutiny in emerging nonclinical neurotechnology ecosystems (e.g., [12]).

A second zone stems from the convergence of neurotechnology with AI, digital platforms, and biometric infrastructures. Affective-computing pipelines are one of several routes through which neurodata may support mental-state inference [13]; neural signatures may also serve as biometric identifiers. Such convergence blurs regulatory boundaries and creates

systemic, population-level complexity. Device-level oversight, still the dominant regulatory template for neurotechnology, is poorly matched to this complexity.

A third zone concerns coordination across institutions and jurisdictions. Neurotechnology governance does not evolve in a geopolitical void: regional differences in cultural, institutional, regulatory, and industrial traditions shape distinct configurations of governance pressure.^{xi} In this context, institutional speed and coordination also become governance variables. Responsible innovation depends not only on defining safeguards, but also on aligning research, regulation, clinical adoption, reimbursement schemes, industrial capacity, and capital allocation quickly and coherently enough for beneficial applications to remain viable.

Against the backdrop of health as a human right^{xii} and growing policy attention to brain health,^{xiii} these pressures are not evenly distributed. They may concentrate among people with disabilities, patients, or individuals dependent on neurotechnology, shaping exposure to risks, access to benefits, continuity of care, and effective safeguards. Participatory approaches can therefore function as operational mechanisms, not only as normative commitments. Affected users surface failure modes that trial endpoints miss, and their inclusion in advisory and post-

market review structures can generate evidence for efficient **calibration**, which would otherwise be unavailable.

The operational turn: from principles to implementation

The movement from the articulation of principles to implementation is not new, being already well established in **science and technology studies (STS)** and in frameworks such as **responsible research and innovation (RRI)** and **anticipatory governance**. What is distinctive here is the unique trajectory of neurotechnology. Few emerging technologies have generated so dense a normative vocabulary so early and against such a thin base of deployment and institutional infrastructure. A substantial body of ethical and legal scholarship has clarified the core concerns, including threats to mental privacy and integrity, to autonomy, and to fair access [2,14], stressing that the field does not lack a normative vocabulary. What it lacks are the institutional conditions needed to make those commitments work. The operational turn is therefore not about abandoning principles, but about translating an unusually rights-dense normative landscape into credible, context-sensitive governance.

This evolution is visible along three interrelated axes. First, there is a *gap between normative maturity and operational capacity*. The central question is no longer only what neurotechnology governance should protect [13,14], but how governance can function across settings marked by uneven institutional capacity, evidentiary uncertainty, fragmented oversight pathways, and divergent incentives. Tools for impact assessment, monitoring, validation, enforcement, and post-deployment review remain underdeveloped or unevenly distributed, especially outside established clinical pathways. Operationalization also intersects with broader policy strategies aimed at shaping technological ecosystems, including industrial policy, research

Box 1. From protection to enablement: calibrating risks and opportunities

Neurotechnology governance is not only about preventing harm. It also shapes whether beneficial applications are supported, delayed, or foreclosed under conditions of uncertainty. This matters across a wide range of therapeutic, assistive, scientific, and potentially cognitive-supportive uses (e.g., [8–11]).

For this reason, the governance of neurotechnology cannot be framed only as restraint. Regulatory choices also influence which actors can develop, test, and scale neurotechnology and under what conditions. In some cases, poorly calibrated regulations may disadvantage smaller or less well-supported entrants, even while appearing protective.

The challenge, then, is not simply whether to intervene, but how to calibrate interventions across settings in which both harms and opportunities are unevenly distributed. In neurotechnology, both overreaction and inaction may shape technological trajectories in lasting ways.

funding, infrastructure development, and innovation-enabling regulation.

Second, governance must become more *sensitive to context*. The contrast between clinical and nonclinical domains makes this especially clear. In clinical and assistive settings, some neurotechnologies offer significant and concrete benefits that may justify higher tolerances for uncertainty and risk. Speech neuroprostheses, for example, can restore communication in people with severe impairments (e.g., [8,9,15]). By contrast, nonmedical neurotechnology presents a more heterogeneous and often less well-validated landscape. Consumer electroencephalography (EEG)-based devices [1,4], neuroadaptive applications [11], and systems claiming to infer attention, fatigue, or emotional state in workplace,^{xiv,xv} educational,^{xvi,xvii} or digital platform^{xviii} environments raise sharper questions about evidentiary validity, downstream use, consent, and governance fit. Higher-risk applications such as nonmedical implantable devices raise further concerns, where invasiveness combines with contested benefits and may justify stronger human-rights-oriented constraints [6]. While human rights are not implementation tools in themselves, they serve as floors below which calibration should not go, particularly given concerns about long-term device support, maintenance obligations, and the risk of **neuroabandonment**.^{xix}

Third, governance can *no longer be framed only in terms of restraint*. Risk-oriented regulation remains essential, but an exclusively defensive approach is insufficient. Neurotechnology governance also concerns the conditions under which enabling and beneficial applications can emerge, gain legitimacy, and scale responsibly. Institutional support, regulatory clarity, incentive alignment, public trust, and the meaningful involvement of affected individuals—who may be uniquely positioned to identify harms related to the misinterpretation of mental states, loss of

agency, or epistemic marginalization—are not external to governance in this domain; they are part of the governance task itself. Properly calibrated neurotechnology governance can therefore do more than constrain undesirable uses: it can reduce uncertainty, support responsible innovation, and strengthen the conditions under which beneficial neurotechnologies become viable and trustworthy (Box 1).

Concluding remarks

An operational turn does not mean that ethical and legal principles [2,14] have become irrelevant, but rather that active implementation must be directly aligned with principled articulation. For neurotechnology, principled articulation has carried disproportionate weight relative to implementation. This balance is now shifting. Table 1 summarizes the main analytical layers of this turn.

The three operational axes pull against one another, and working within them requires managing tensions, not necessarily resolving them. Two of these are worth spelling out. Calibration is the first: assessment tools must be sensitive enough to separate a clinical implant from a workplace headset, yet standardized enough to travel between them. Enablement is the second, and it cuts against capacity: it runs on the speed of deployment, while institutional capacity is built on a slower clock, so caution calibrated to protect patients can foreclose the very applications that would serve them.

These trade-offs mark where the next phase of work lies. Comparative case studies that trace a neurotechnology across clinical, consumer, workplace, and other implementation pathways would reveal which governance mechanisms transfer across those pathways and which fail at their boundaries. The successes and failures of the operational turn, therefore, offer a tractable agenda for the future.

Notes

¹For the purpose of this article, neurodata will be understood following UNESCO's definition for neural data within its Recommendation on the Ethics of Neurotechnology: 'Neural data include qualitative and quantitative data about the structure, activity and function of the nervous system gathered through neurotechnology [1]. These are the most direct measurements or observations of nervous system states, many of which are correlated with mental states. They encompass data relating to a nervous system's activity, including both direct measurements of neuronal structure, activity and/or function (e.g., neuronal firing or averaged bioelectric signals from EEG) and indirect functional indicators (e.g., blood flow in fMRI and fNIRS).'

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this article, the authors used large language model-based artificial intelligence tools (ChatGPT-5.5 and Claude Opus 5) to support editorial revision and improve language clarity. The authors carefully reviewed and edited the article after using these tools and take full responsibility for the final content of the publication.

Resources

ⁱ<https://theconversation.com/the-neurotechnology-shift-how-next-generation-wearables-interface-with-the-brain-itself-272741>

ⁱⁱwww.unesco.org/en/ethics-neurotech/recommendation?hub=83294

ⁱⁱⁱwww.bcn.cl/leychile/navegar?idNorma=1166983

^{iv}www.congress.gov/bill/119th-congress/senate-bill/2925/text

^v<https://cset.georgetown.edu/publication/china-bci-ethics/>

^{vi}<https://unesdoc.unesco.org/ark:/48223/pf0000394866>

^{vii}www.cinetcenter.com/en/inegov/cinet-neurotechnology-conference/

^{viii}www.cinetcenter.com/en/inegov/the-observatory/

^{ix}<https://hsph.harvard.edu/research/onnella-lab/research-areas/>

^x<https://cfg.eu/promise-and-peril/>

^{xi}www.gcsp.ch/publications/neurotechnologies-new-frontier-international-governance

^{xii}www.who.int/news-room/fact-sheets/detail/human-rights-and-health

^{xiii}www.who.int/health-topics/brain-health

^{xiv}<https://hbr.org/2023/03/neurotech-at-work>

^{xv}www.wencomine.com/our-solutions/safety

^{xvi}www.wsj.com/articles/chinas-efforts-to-lead-the-way-in-ai-start-in-its-classrooms-11571958181

^{xvii}www.theguardian.com/world/2019/nov/01/chinese-primary-school-halts-trial-of-device-that-monitors-pupils-brainwaves

^{xviii}www.alterego.io/

^{xix}www.nature.com/immersive/d41586-022-03810-5/index.html

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