

Unprotected Minds: A Clinical Neuropsychology Perspective on the Ethics of Emerging Neurotechnologies

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ABSTRACT: The rapid expansion of EEG-based neurotechnology from clinical and research settings into consumer and workplace environments has created new ethical challenges regarding the interpretation and governance of neural data. While clinical applications operate under strict therapeutic intent and expert oversight, and research is similarly governed by rigorous ethical and regulatory frameworks, non-clinical uses often rely on simplified metrics, unclear consent processes, and inadequate safeguards. This review goes beyond a narrative approach by examining the ethical gaps that arise when EEG-based technologies operate across divergent contexts. Through a biomedical ethics framework, the analysis reveals a critical failure to protect both neural signals and their interpretation once these technologies move outside the clinic. Central to this issue is the critical role of the clinical neuropsychologists, whose expertise enables contextualizing the neural signals while preventing the oversimplification of EEG data, and the overgeneralization of probabilistic brain markers. The findings underscore implications for three key stakeholder groups: neuropsychologists, who can establish interpretative standards; the BCI community, which is critical for ensuring the scientific validity and transparency of EEG-inferred cognitive states; and policymakers, who must address the regulatory gaps by extending protections beyond neural data collection.

INTRODUCTION

The applications of neurotechnology are rapidly shifting from the sterile confinement of the clinical and research setting to the unregulated expanse of the consumer market. Historically, neurotechnology systems utilizing electroencephalography (EEG) appeared as specialized tools, one example being their use in neurorehabilitation to restore motor and cognitive functions in patients with neurological deficits [1]. These systems are defined as technologies that acquire and process neural signals to measure cognitive or symptom-related activity, or generate external control signals. Their operational modes are diverse, from real-time applications like neurofeedback and brain-computer interfaces (BCI) control to continuous EEG-based neurotechnology, which may occur with or without the

user's awareness [2].

However, with improvements in the accessibility of EEG driven by low-cost, wireless headsets, and dry-electrode sensors that eliminate the need for gels, these technologies have recently been propelled into non-clinical and non-research settings. Applications range from wellness devices, gaming, to even workplace surveillance [3, 4]. While these advancements promise a new era of human-computer interaction, where neurotechnology becomes integrated into daily life, they simultaneously expose a critical gap in ethical and legal protection, namely the privacy of the mind itself [5].

Addressing this gap, the current paper investigates the following research question: What are the ethical challenges associated with EEG-based neurotechnology systems in clinical applications compared to their application in non-clinical settings? To date, the discourse on “neurorights” has been led by legal scholars, but the perspective of clinical neuropsychology is urgently needed [6]. With their expertise in interpreting neural data and validating it through behavioral and contextual assessment, clinical neuropsychologists are uniquely positioned as specialists in diagnostics and cognitive evaluation. Their role extends beyond treatment, as they are not only clinicians who assess and interpret brain function but also critical advocates for the ethical protection of neural information, ensuring its responsible use and interpretation. Therefore, the aim of this paper is to identify the ethical gaps in the uses of these systems in these two diverging settings and argue for the inclusion of neuropsychological expertise in neuroethical policy-making.

METHODS

A narrative literature review was conducted to examine the ethical implications of EEG-based neurotechnology across clinical and non-clinical contexts. Papers were selected through searches in databases such as PsycINFO, PubMed, and Google Scholar using combinations of keywords (EEG, neurotechnology, BCI, consumer neurotechnology, and neuroethics). The identified literature was then analyzed using the biomedical ethics framework proposed by Beauchamp and Childress [7].

CLINICAL APPLICATIONS

EEG-based neurotechnology systems are primarily employed to research, assess, restore, or compensate for loss of function [1]. In this context, the purpose of EEG-based neurotechnology is grounded in its research or therapeutic intent. In clinical practice, these systems are useful in both diagnosis and intervention across a wide range of conditions, including epilepsy, stroke, attention-deficit/hyperactivity disorder (ADHD), and depression [8, 9]. For example, neurofeedback represents a thoroughly researched application in which individuals learn to modulate specific patterns of brain activity associated with cognitive or emotional functioning [10, 11]. A meta-analysis of ten studies has shown that neurofeedback can yield sustained symptom remission in the treatment of ADHD [12]. Similarly, BCIs have been developed to assist patients with impairments by translating neural signals into external actions, such as controlling a robotic arm to perform grasping movements [13].

Technical Validity and Interpretation of Brain Signals

Underlying these applications is the strict requirement that data acquisition must occur in highly controlled environments. This necessity can be further explained by the concept of signal-to-noise ratio which is the proportion of meaningful brain activity relative to unwanted interference [14]. In this context, noise refers to any non-neural electrical activity that contaminates recordings, such as power lines interference or biological artifacts like muscle tension or eye blinks [14]. Because the brain's electrical signal is naturally weak, artifacts create a low signal-to-noise ratio, where meaningful data can easily be drowned out by interference. Consequently, clinical settings must employ standardized protocols and carefully managed conditions to minimize these confounding variables, ensuring that the recorded activity reflects actual neural data rather than external noise [14].

Equally important is the role of expert interpretation because neural data does not carry intrinsic meaning and its interpretation is not intuitive. Instead, signals serve as indirect proxies for underlying brain function, requiring contextualized analysis by trained clinicians who understand both the limitations of the measurement and the clinical characteristics of the patient [14, 15]. These factors highlight that neural signals are probabilistic and context-dependent, not transparent windows into one's thoughts and intentions [16]. Ethical and scientific literature consistently emphasizes that current neurotechnology cannot reliably access beliefs, desires, intentions, or individual thoughts [17].

Regulatory Frameworks and Patient Protections

Because these technologies are used to measure and interpret brain activity, they are regulated as medical

devices and must demonstrate safety, efficacy, and clinical relevance. In the European Union (EU), this occurs under the Medical Device Regulation (MDR) 2017/745, which requires clinical evidence, risk assessment, and post-market surveillance [18].

In parallel with device regulation, data protection laws play a central ethical role. Under the EU General Data Protection Regulation (GDPR) 2016/679, neural data falls within the category of “special category data” requiring explicit justification, data minimization, and heightened safeguards [19]. These protections limit secondary uses of neural data and reinforce patient control over how their information is stored, processed, and disclosed. This is a crucial safeguard given the intimate nature of the brain-derived information [20]. While current technology cannot decode complex thoughts, it can nonetheless infer sensitive attributes such as emotional states, cognitive health, and precursors to neurological disease [5].

Informed consent constitutes an additional cornerstone of clinical EEG-based neurotechnology. Patients as well as research participants are typically informed about the purpose of monitoring, the nature of the data collected, potential risks, and anticipated benefits prior to participation [21]. Therefore, clinical guidelines emphasize the responsibility of clinicians to assess decision-making capacity, adapt explanations accordingly, and involve proxies or guardians when appropriate [22].

It is evident that clinical neuropsychologists occupy a distinctive position at the intersection of neural data and human vulnerability. Their specialized training allows them to interpret neural signals within the broader context of the individual, integrating behavioral, cognitive, and situational factors, thereby minimizing the risk of overinterpretation of probabilistic neural markers [23]. Within neuropsychological clinical practice and research, neural data is never treated as a standalone indicator of identity or intent but as one component of a comprehensive assessment focused on patient care and rehabilitation [17].

NON-CLINICAL APPLICATIONS

In recent years, EEG-based neurotechnology has increasingly migrated from research and clinical contexts into non-clinical environments, including workplaces and consumer markets. Technologies originally developed for diagnosis or treatment are now deployed to assess attention, fatigue, engagement, or cognitive performance in healthy individuals [3, 24]. This marks a fundamental shift in purpose, from understanding or restoring impaired function to measuring or improving cognition in everyday life. However, as these systems move into everyday environments, the ethical significance of who interprets neural data and for what purpose demands urgent attention.

In workplace settings, EEG-based neurotechnology has been introduced primarily in high-risk environments. For example, EEG-based headsets have been used in China

to detect in real-time fatigue, stress, or lapses in concentration [24, 25]. Similarly, in mining and construction industries, workers have been documented to use “smart helmets” that are designed to prevent accidents by detecting exhaustion before performance deteriorates [3]. In these contexts, EEG-based neurotechnology is often framed as protective rather than punitive, aiming to identify risks before harm occurs. However, the use of continuous neural surveillance in environments characterized by strong power asymmetries is ethically complex, as workers may have limited ability to reduce participation without facing negative consequences [24].

In the consumer market, the Muse headband is an application serving the goal of self-optimization. It is marketed as a personal meditation tool as the device utilizes dry sensor EEG to provide real-time neurofeedback by translating the user’s brain activity into sounds [26]. The device plays calm weather sounds during periods of focus, but switches to stormy winds when the user loses concentration. Consequently, this technology reframes mindfulness as a form of neuro-optimization for productive efficiency [27].

Technical Limitations and Data Interpretation

In non-clinical applications, concerns about validity and interpretations are particularly salient. Consumer-grade and workplace EEG devices rely on simplified processing of neural data that translates complex activity into reductive metrics, such as a single fatigue score [27]. Furthermore, because neural signals are highly sensitive to movement and environmental noise, non-clinical recordings are more susceptible to artifacts, making them less reliable than their clinical counterparts [28]. Considering these limitations, they are not suited to support decisions about performance, safety, or employability [30]. Moreover, the implications for well-being differ markedly from those observed in healthcare contexts. Continuous monitoring may foster stress and self-censorship, particularly when individuals are aware that their neural states are subject to external scrutiny [5].

Regulatory Gaps

The regulatory framework governing EEG-based neurotechnology changes substantially once these systems move outside clinical environments, creating an uneven level of protection across contexts. In non-clinical settings, the applicability of existing data protection frameworks, including the GDPR, may also become less clear when neural data is collected outside medical contexts [3, 19]. Moreover, while clinical applications fall under the MDR [18], consumer and workplace applications typically fall under broader consumer protection and product safety frameworks, such as the General Product Safety Directive (2001/95/EC) and the Unfair Commercial Practices Directive (2005/29/EC) [30, 31]. These frameworks address the prevention of unsafe products and misleading

commercial claims. However, they were not designed to regulate technologies that monitor neural activity, resulting in a lower regulatory threshold than in clinical contexts.

When artificial intelligence (AI) systems are used to infer cognitive states such as attention, fatigue, or emotional engagement, additional regulatory frameworks may also apply. The EU AI Act (Regulation EU 2024/1689) introduces obligations for high-risk AI systems, particularly in employment and biometric contexts [32]. However, when these systems are not specifically marketed as AI decision making technologies, it is uncertain how consistent this framework will be applied. Consequently, EEG-based neurotechnology that functions simultaneously as a wearable device and an algorithmic inference system may remain subject to fragmented regulatory oversight, despite producing inferences about cognitive states [6]. This raises concerns about both the reliability of neural interpretations and the potential consequences of decisions based on such data.

AN ETHICAL PERSPECTIVE

The moral acceptability of EEG-based neurotechnology depends not only on the usefulness of the technology itself, but on the conditions under which neural data is generated, interpreted, and acted upon. While clinical and non-clinical applications frequently rely on similar tools, they diverge fundamentally in intent, governance, and epistemic reliability. To evaluate these divergences, the following analysis adopts the framework of biomedical ethics proposed by Beauchamp and Childress [7], specifically examining how the transition from clinical to consumer settings challenges the principles of beneficence, non-maleficence, autonomy, and justice (Fig. 1). This medical ethics model was selected because neurotechnology systems originate in clinical practice and involve the measurement of brain activity, which has traditionally been governed by medical standards of care.

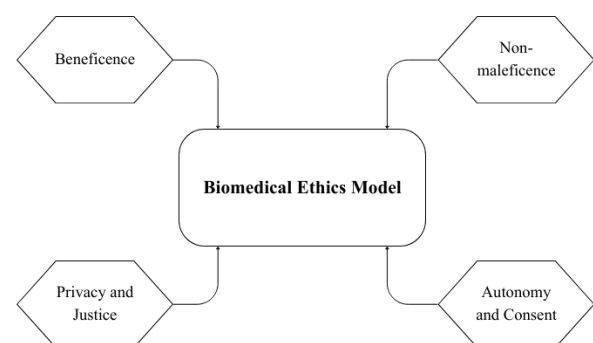


Figure 1: The four principles of the biomedical ethics model.

Beneficence

In clinical contexts, EEG-based neurotechnology systems are anchored in beneficence and epistemic restraint. Despite decades of research and some

efficacious protocols, neurofeedback remains highly variable in its effects, underscoring the need for personalized approaches and deeper investigation into the sources of this heterogeneity [33]. If uncertainty persists even under optimal conditions characterized by validated protocols and expert interpretation, then claims made by non-clinical applications operating outside these constraints warrant heightened skepticism. Unsupported claims based on neural signals may mislead users about their cognitive states and lead them to make decisions about their health based on unreliable information.

Non-Maleficence

This epistemic gap is illustrated by comparative research on two medical-grade and two consumer neurodevices. Ratti et al. [28] found that under specific controlled conditions and when interpreted by trained experts, one of the consumer EEG devices produced signals comparable to the medical-grade equipment. Crucially, this equivalence depended on the laboratory-level control and expert analysis, conditions which are rarely met in real-world consumer and workplace environments. This raises concerns regarding non-maleficence, as users may be penalized or judged based on technically flawed data. When imperfect algorithms generate false results, users face the risk of unjustified punishment based on flawed data.

Autonomy and Consent

Autonomy and consent further differentiate clinical from non-clinical uses. In research and healthcare, informed consent is treated as an ongoing ethical process, shaped by sensitivity to vulnerability and voluntariness [7]. Clinical neuropsychologists and researchers are trained to explain limitations and potential non-response to interventions such as neurofeedback, ensuring that patient's expectations remain realistic. In contexts outside of scientific research and clinical application, by contrast, consent is frequently embedded in employment contracts or terms of use. Thus, consent may be legally valid yet ethically compromised, as individuals face structural pressure that limits their ability to refuse to participate without social or economic cost [3].

Privacy and Justice

The principles of privacy and justice are linked to data ownership. In clinical settings, neural data is strictly defined as a medical record, owned by the patient and protected against discrimination. In consumer and workplace settings, however, neural data is often a proprietary asset, stripping individuals of ownership rights [5]. This shift creates risks of discrimination that can be used to deny employment [24]. Without the protection of medical confidentiality, the secondary use of neural data violates the principle of justice by prioritizing corporate interests over the fair treatment of the individual.

DISCUSSION

The present narrative review examined the ethical challenges that arise as EEG-based neurotechnology expands beyond clinical and research environments into consumer and workplace contexts. Through a biomedical ethics framework, it highlights the urgent need to incorporate the expertise of clinical neuropsychologists whose training in contextualizing neural data and validating it with behavioral and diagnostic insights is essential for mitigating risk of misinterpretation, overgeneralizing, and unethical application. Outside these frameworks, however, EEG data is only translated into reductive metrics. While the emerging neurorights discourse has emphasized protections for mental privacy and cognitive liberty, ethical risks arise also regarding the interpretation of the neural signals [5].

Implications for Neuropsychologists

Clinical neuropsychologists play an important role in ensuring that neural signals are interpreted within appropriate psychological and functional contexts. Their expertise lies in integrating neural indicators while recognizing the limits of neural data and the broader needs of the individual. In clinical practice, EEG is not a standard tool and, when used, plays a secondary role. Its findings are always interpreted alongside neuropsychological data, patient history, and environmental context. This contrasts sharply with the oversimplified or isolated use of EEG in non-clinical settings.

Although guidelines exist for neural interpretation within clinical settings, comparable standards are absent in non-clinical contexts. Neuropsychologists may therefore contribute by helping develop interpretative standards that prevent the overinterpretation of probabilistic neural markers for these emerging applications. In addition, their experience makes them well-suited to provide third-party evaluation when neural metrics are used to inform consequential decisions about individuals' performance, well-being, or cognitive functioning. Beyond clinical practice, their expertise may also contribute to the development of ethical guidelines and policy discussions concerning the interpretation and protection of neural data outside healthcare contexts.

Implications for the BCI Community

These developments carry important implications for the BCI community. As EEG-based neurotechnology becomes more integrated into consumer environments, the challenge lies not only in measuring neural signals but in ensuring that the interpretive claims derived from those signals remain scientifically justified. For the BCI community, maintaining the scientific integrity of neural inferences when EEG leaves the laboratory therefore becomes a shared concern.

In this regard, the principles of open and reproducible science offer a useful framework. Systems that claim to

infer cognitive states should be held to standards comparable to those applied within scientific research. This includes communicating the evidentiary basis for neural inference claims as well as documenting the interpretative pipeline from signal acquisition and preprocessing to algorithmic classification and behavioral inference [34]. As neurotechnology increasingly moves beyond the laboratory, aligning real-world applications with the norms of scientific validation will be essential for maintaining public trust and ensuring BCIs truly benefit the users.

Implications for Policy Makers

Neurotechnology governance should move beyond regulating the collection of neural data and address how such data is interpreted and used to generate inferences about an individual's cognitive states. Current regulatory frameworks remain fragmented, with device safety, data protection, and algorithmic systems governed through separate legal protections. While regulations such as the GDPR provide strong protections for health-related data, neural data generated outside the clinic may be susceptible to different standards [3, 19]. Policymakers should therefore clarify the legal status of neural data and ensure that protections extend to neural inferences and downstream decision-making, particularly in workplace and consumer environments where individuals have limited control over how their cognitive data are interpreted or used. In developing such governance frameworks, policymakers should engage with scientific or clinical experts who possess the expertise necessary to evaluate the validity and limitations of EEG-based systems and the interpretations derived from them.

CONCLUSION

This review highlights that the migration of EEG-based neurotechnology from research and clinical environments into consumer and workplace contexts has created a significant ethical divide. Within clinical practice, neural signals are interpreted within structured frameworks that emphasize therapeutic intent, standardized protocols, and expert oversight. In non-clinical and non-research applications, neural signals are translated into simplified metrics that claim to represent complex cognitive states.

This shift introduces ethical risks that extend beyond questions of data privacy. Neural signals are inherently probabilistic and context-dependent, yet consumers and workplace applications may present them as clear indicators of attention, fatigue, or mental performance. When such interpretations guide decisions about productivity or well-being, the absence of clinical expertise and robust validation becomes ethically problematic.

Addressing these challenges requires collaboration between scientific, clinical, and regulatory communities. Neuropsychologists can contribute expertise in the holistic and contextual interpretation of neural signals,

the BCI community plays a key role in maintaining standards for the scientific validity of EEG systems and the neural inferences derived from them, and policy makers should ensure that the regulatory frameworks address not only the collection of neural data, but also the interpretations and decisions derived from it.

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