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ETHICS OF TECHNOLOGY-ASSISTED NEUROCOGNITIVE REHABILITATION

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Introduction

Integration of technology into healthcare has significantly transformed neurocognitive rehabilitation. Artificial intelligence (AI), machine learning, and aligned technologies have rapidly reshaped the domain of neurocognitive rehabilitative care (Calderone et al., 2024). Transformative technologies enables early disease detection, personalized cognitive training programs, and intelligent virtual therapists to help patients recover brain functions lost to injury, stroke, or degenerative disorders (Al Kuwaiti et al., 2023; Calderone et al., 2024; Loya et al., 2025).

The ethics of integration of technology into neurocognitive rehabilitation is a complex problem. The problem needs to be defined systematically and understood systemically. For example, AI is reshaping neurocognitive rehabilitation through personalized insights and precise monitoring. While it enhances therapy, it also raises concerns around data privacy, consent, and the replication of human qualities like empathy and trust. As AI becomes more integrated into care, ethical and human-centric approaches are essential to ensure its responsible and compassionate use. Similarly, other transformative technologies like wearable devices and brain interfaces provide effective and real-time insights and efficacy through predictive capabilities in neurocognitive rehabilitation (Reddy, 2025). The integration of the new technologies in neurocognitive rehabilitation has facilitated the development of effective treatments, compensatory strategies, and real-world simulations (Charchat-Fichman et al., 2014).

Technology-based interventions ensure in delivering personalized neurocognitive rehabilitation and improving patient outcomes. However, challenges like lack of standardization, limited generalizability, integration hurdles, and ethical concerns ranging from data privacy to equitable access must be carefully addressed before these solutions can be widely adopted (Morris et al., 2025). They present novel challenges to balancing the four pillars of beneficence, non-malfeasance, justice, and autonomy (Kelly & Leff, 2023). The World Health Organization (2024) guidance on "Ethics and Governance of Artificial Intelligence for Health: Large Multi-Modal Models" is narrowly focused on one technology – AI, and

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broadly focused on health – not just rehabilitation. It is a consensus recommendation from 20 experts but does not provide a logical framework that can be tailored to the challenge at hand.

Ontology of Ethics of Technology-Assisted Neurocognitive Rehabilitation

We present a framework to describe the challenges, explain the logic, set the expectations, and regulate the outcome of the ethics of technology-assisted neurocognitive rehabilitation. The framework will help address the issue systemically and systematically. In the absence of such a framework, the present approaches are selective, siloed, and segmented and do not address the challenges holistically as they should be. The "Ontology of Ethics of Technology-Driven Neurocognitive Rehabilitation" encapsulates the core logic of the problem clearly, concisely, and comprehensively. The complex interplay of ethics, efficiency, and effectiveness of technology-assisted neurocognitive rehabilitation can be visualized and analyzed using the framework which is presented in Figure 16.1 and described below.

The application and development of the ontology follow the description of the logic and process as put forth by Ramaprasad and Syn (Ramaprasad & Syn, 2014, 2015). The ontological method has been used to study mental healthcare (Chandra et al., 2024; Martínez et al., 2022), COVID-19 strategies (Sreeganga et al., 2021), public health informatics research (Ramaprasad et al., 2017), and mobile-health research (Cameron et al., 2017).

Neurocognitive Rehabilitation

Neurocognitive rehabilitation is the choice and implementation of suitable interventions based on clinical assessment of the response stage of the patient. The Response Stage, Clinical Interaction, and Intervention dimensions are defined below. The choice and implementation will be by a set of agents, based on the technologies and the objectives of rehabilitation. These three dimensions are defined subsequently.

Response Stage

A patient's neurocognitive rehabilitation intervention must be based on the clinical assessment of the response stage of the patient. The patient's response stage may range from null (or no) neurocognitive response to an appropriate purposeful response. The response scale is based on the RanchoScale (Lin & Wroten, 2022) and appropriately represents the progressive improvement of a neurocognitive rehabilitation patient. The stages of the scale are listed in the column labeled Response Stage in Figure 16.1. They are as follows: null, generalized, localized, confused (agitated, inappropriate, appropriate), and appropriate (automatic, purposeful). The purpose of rehabilitation is to move the patient from an upper stage to a lower stage and eventually to independence.

Clinical Interaction

The determination of the present neurocognitive stage of the patient, the desired stage, and the appropriate intervention to bridge the gap are based on the clinical interaction between the patient and the rehabilitating agent. The clinical interaction must include engagement with the patient, assessment of the patient, documentation of the interaction, diagnosis of

Objective		*Technology*		*Neurocognitive Rehabilitation*							
				*Stage**		*Clinical*		*Intervention**		*Agent*	
Ethics	[of]	Invasive	[technology for]	Null	[clinical]	Engagement	[for]	Total	[intervention by]	Care Provider	[agent]
Personal		Implant		Generalized		Assessment		Maximum		Physician	
Social		Deep brain stimulation		Localized		Documentation		Moderate		Nurse	
Professional		Electrocarticogrphy		Confused		Diagnosis		Minimum		Therapist	
Efficiency		Noninvasive		Agitated		Communication		Standby		Psycho-	
Cost		Cognitive training		Inappropriate		Feedback		Standby on request		Occupational	
Time		Virtual reality		Appropriate				Modified independent		Physio-	
Personnel		Artificial Intelligence		Appropriate						Speech & Hearing	
Informational		Wearable		Automatic						Caretaker	
Effectiveness		Robotic		Purposeful						Self	
Cognitive		Brain interface								Family/Friend	
Conative		Assistive								Professional	
Affective		Prosthetic								Community	
		External								Digital	
		Gaming								Handheld	
		Telerehabilitation								Standalone	
		eHealth									
		Communication									
		Monitoring									

Figure 16.1 Ontology of Ethics of Technology-Driven Neurocognitive Rehabilitation.

*Based on Racnhos scale [Lin K, Wroten M. Ranchos Los Amigos. (2022). In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK448151/]

the stage and determination of the appropriate intervention and its target stage, communication of the diagnosis and intervention with the patient and the rehabilitating agents, and feedback for correction and adaptation to bridge the gap. The steps may be implemented in one appointment or several appointments over an extended period with breaks of several days or weeks. All the appointments must be tracked in the healthcare information system assiduously. These steps are listed in the column labeled Clinical.

Intervention

An intervention may range from being total (maximum) to modified independent (minimal), a step short of the patient becoming independent (no intervention needed). These levels too are based on the RanchoScale (Lin & Wroten, 2022) and appropriately represent the progress of a neurocognitive rehabilitation patient. The intermediate levels of intervention, in descending order of coverage, are maximum, moderate, minimum, standby, and standby on request. The level of intervention for a patient is based on: (a) his/her clinical interaction with the rehabilitating agent to determine the present and desired stages of the patient, (b) the gap between the two, and (c) the associated diagnosis and recommendation of the rehabilitating agent.

Technology for Neurocognitive Rehabilitation

Technology can assist neurocognitive rehabilitation at all levels of intervention and steps of clinical interaction. The choice of technology must depend on the present response stage of the patient, the desired stage, the gap to be bridged, the choice of intervention to bridge the gap, and the clinical interaction. The technology may be invasive, penetrating the skin of the patient; it may be non-invasive, in contact with the skin of the patient but not penetrating it; or external, removed from the skin of the patient. The three types of technology and their subtypes are listed in the column labeled Technology (Figure 16.1). These technologies can perform specialized functions to drive interventions at different response stages and assist in the steps of clinical interaction, and the general functions to support the rehabilitation. For instance, integration of technology into neurocognitive rehabilitation intervention been effective in facilitating goal performance and satisfaction for individuals with memory problems (Grewal et al., 2025).

Agents of Neurocognitive Rehabilitation

The choice of assistance technologies must be determined by the agents delivering the rehabilitation in consultation with the patient. The agents, listed in the last column labeled Agent, may be care providers, caretakers, and digital tools. The care providers are physicians, nurses, therapists (psychotherapists, occupational therapists, physiotherapists, and speech and hearing therapists); the caretakers are the self, families/friends, professionals, and the community; and the digital tools may be handheld or standalone. These agents may act individually, as a team, and in coordination for neurocognitive rehabilitation.

The objective in choosing a technology for assistance is to balance the ethics of the choice with its efficiency and effectiveness in rehabilitation. The ethics determining the choice must include the following: (a) the personal ethics of the agent and the recipient, (b) the social

ethics in the context of rehabilitation, and (c) the professional ethics of the rehabilitating agents. The ethics of a choice can affect the cost, time, personnel, and informational efficiency of rehabilitation; it may also affect the cognitive, conative, and affective effectiveness of the same. These choices must be guided by personal, social, and professional guidelines.

Objectives of Neurocognitive Rehabilitation

Technology – invasive, non-invasive, and external – to assist neurocognitive rehabilitation is advancing rapidly. It can improve the efficiency and effectiveness of rehabilitation. Yet, because of the very novelty and nascency of application of many of these technologies, their unintended, uncommon, and potentially long-term effects on the body and mind of the rehabilitated patient and the rehabilitating agent are unknown. The challenge, choice, and application of a technology may be further compounded by the neurocognitive state of the patient, and his/her ability to provide informed consent. In the following we discuss the tradeoffs between ethics of technology-assisted neurocognitive rehabilitation and the effect of the assistance on the efficiency and effectiveness of rehabilitation.

Ethical Challenges of Technology-Assisted Rehabilitation

The ethical challenge of technology-assisted neurocognitive rehabilitation of a patient by an agent can be defined using the ontology to:

- Specify the rehabilitation requirements of a patient in terms of:
  - The clinical steps;
  - The present and desired response stages, and the gap between them; and
  - The recommended interventions.
- Specify the technology assistance for the interventions.
- Specify the agent(s) for the interventions.
- Specify the ethical requirements of the technology-assisted interventions, and the tradeoff between the ethics, efficiency, and effectiveness of the interventions.

Invasive, non-invasive, and external technologies pose different sets of ethical issues that are distinctive and overlapping. The following discussion is organized around the three types. Within each section we discuss the ethical issues for care providers, caretakers, and digital agents.

Ethics of Technology-Assisted Neurocognitive Rehabilitation

The ethics of technology-assisted neurocognitive rehabilitation is complex because of the following characteristics of the interventions:

- The interventions act physiologically on the neurology of the patient, sometimes deep within the brain. Invasive technologies penetrate the deepest, non-invasive technologies far less, and external technologies not at all.
- The interventions act psychologically on the cognition of the patient, sometimes in fundamental ways. Invasive technologies can affect the psychology most fundamentally, non-invasive technologies less so, and external technologies the least.

- All three types of intervention technologies are advancing rapidly and developing new capabilities to intervene neurologically, cognitively, and externally. It takes time to establish their effectiveness. While external technology may be preferable to a non-invasive technology, and a non-invasive technology to an invasive technology, the trade-off between their effectiveness and efficiency may not be clearcut and hence the choice is difficult. The ethics of the choice will compound the difficulty.
- While the rehabilitation intervention may be narrowly focused, it can affect the patient's body and mind in their entirety. The ethics must consider these larger effects.
- Many of the technology's effects may be irreversible and unpredictable, especially in the long-term. The irreversibility/unpredictability is likely to be greatest for the invasive technologies, less for the non-invasive ones, and least for the external ones.
- The agents of intervention and the patients must decide upon the ethics of an intervention based on incomplete knowledge of its efficiency and effectiveness. The choice between the promise of technology must be weighed against the perils of ignorance about the outcomes must be made ethically by the agent and the recipient. Incorporation of patient feedback to enhance the overall effectiveness of and personal relevance of rehabilitation programs is critical (Reddy, 2025).

We discuss the implications of the above characteristics for the invasive, non-invasive, and external technologies for the ethical considerations of the care providers, caretakers, and digital agents in the following sections.

Ethics of Invasive Technology-Assisted Neurocognitive Rehabilitation

Invasive technologies for assisting neurocognitive rehabilitation include implants, deep brain stimulation, and electrocorticography. ICT-based programs for neurocognitive rehabilitation show promising results in improving cognitive functions such as attention, memory, and executive functions (Geraldo et al., 2018). While Brain–Computer Interface (BCI)–AI integration has witnessed greater expansion, there is a need standardized evaluation protocols, ethical global governance frameworks, formulation of guidelines for engaging in cutting-edge research, and an interdisciplinary collaboration (Qiu et al., 2024; Rudroff, 2025; Wang et al., 2024). For instance, there is the need for newer neuro-rights as part of ethical governance principles for integration of AI and BCI (Astobiza et al., 2019). Mental privacy and data security are crucial ethical concerns in integration of AI with BCIs, especially when there are risks of accessing intimate neural data without consent. There is a need for robust security measures to protect cognitive liberty and personal information as these technologies progress (Rudroff, 2025).

Care Provider, Caretaker, and Digital Agent Ethics for Invasive Technology

The care providers, caretakers, and digital agents of invasive technology-assisted neurocognitive rehabilitation bear a heavy responsibility in balancing the four pillars of beneficence, non-maleficence, justice, and autonomy (Kelly & Leff, 2023). Their challenge is compounded by: (a) unclear and emerging guidance on the personal, social, and professional ethics, (b) uncertainty and lack of trusted information about the cognitive, conative, and affective outcomes of the intervention, and (c) unpredictability and lack of adequate evidence about the cost, time, personnel, and other resource requirements regarding the

technology. Further, there is a significant asymmetry in the information possessed by the care providers, caretakers, and digital agent – the care providers have the most trusted information, the caretakers less, and the digital agents the least. The open-source information available to the caretakers to make their choice is likely to be limited, and when available technical and difficult to understand for the layperson. Thus, the care providers have the primary responsibility for assuring the ethics of invasive technology-assisted neurocognitive rehabilitation. In addition to assuring their own ethics, they must assist the caretakers in their choice, and in guiding the digital agents' design to be ethical. Thus, the ethical requirements are as follows:

- The care providers must describe and explain to the patient and the caretakers the clinical steps, their purpose, and timeline.
- They must agree on the present and desired response stages, and the gap between them in consultation with the patient and the caretakers.
- They must agree on the recommended interventions, again in consultation with the patient and the caretakers.
- They must arrive at a consensus on the technology assistance for the interventions, and the agents that will be administering the interventions.
- In the above consultation, consensus generation, and implementation and the trade-off between the ethics, efficiency, and effectiveness of the interventions must be clarified amongst the concerned agents. The beneficence of the intervention and its non-maleficence must be considered, considering the likely diminished autonomy of the patient requiring the intervention.

Further, technology-assisted invasive neurocognitive rehabilitation will require super specialists; it is likely to be expensive, and not widely accessible. Consequently, ethically affirming justice in the delivery of such rehabilitation will be a challenge.

Ethics of Non-invasive Technology-Assisted Neurocognitive Rehabilitation

Non-invasive technologies for assisting neurocognitive rehabilitation include cognitive training, virtual reality, AI, wearable devices, robotics, brain interfaces, assistive technologies, and prosthetics.

The need for integrative approaches to enhance cognitive rehabilitation through assistive technology, telerehabilitation, and virtual reality has been well articulated (Stasolla et al., 2023). Robotic therapies have proven significant improvements cognitive and motor domains of neurocognitive rehab care (Morris et al., 2025). The need for advanced robotic assessment of neurologic impairments in case of traumatic brain injury cases are prerequisites for measuring motor and cognitive assessments (Debert et al., 2012). Healthcare robots can benefit mental health, physical rehabilitation, and general well-being (Boch & de Clermont-Tonnerre, 2024). Nonetheless, the challenges for robot-assisted cognitive trainings include ethical issues, user-centric design, reliability concerns, trust, and cost-effectiveness (Yuan et al., 2021).

Ethical conundrums in the use of robotics and the appropriateness of its use for children and elderly population are specifically discussed. Novel smart home care models for elderly population require robotic designs that are optimized, improved flexibility, feasibility, better sensor networks, and assistance from diverse technologies (Zhao & Guo, 2023).

Reference and adherence to ethical principles for devising treatment modalities could be considered acceptable (Majeed, 2016).

Data security and privacy are critical components of assistive technologies. For instance, the principles outlined in iManus offer a foundation for ethically designing robotics in remote healthcare (Maddahi et al., 2022). Further, the advantages of having smart mobility aids like the cloud-connected prosthetics with robotic exoskeletons are in terms of effective communications, remote customization, real-time data analysis, and adaptive learning (Zhang et al., 2024). However, limited research and attention have been directed toward the ethical considerations involved in the development and clinical translation of prosthetic technology (Gavette et al., 2023).

Care Provider, Caretaker, and Digital Agent Ethics for Non-invasive Technology

The requirements for assuring the ethics for non-invasive technology are like that of invasive technology but potentially less stringent. This is due to the easier reversibility and predictability of the effects of these interventions.

The care providers, caretakers, and digital agents of non-invasive technology-assisted neurocognitive rehabilitation bear a lighter responsibility in balancing the four pillars of ethics because of: (a) clearer and documented guidance on the personal, social, and professional ethics, (b) greater certainty and more trusted information about the cognitive, conative, and affective outcomes of the intervention, and (c) greater predictability and better evidence about the cost, time, personnel, and other resource requirements regarding the technology. Further, there is a lesser asymmetry in the information possessed by the care providers, caretakers, and the digital agent. The open-source information available to the caretakers to make their choice is less limited, and easier to understand for the layperson. Thus, the care providers share the responsibility for assuring the ethics of non-invasive technology-assisted neurocognitive rehabilitation. As with invasive technology, the care providers in addition to assuring their own ethics must assist the caretakers in their choice, and in guiding the digital agents' design to be ethical.

Thus, the procedure for fulfilling the ethical requirements is like that with the invasive technology. The steps are likely to be easier because of greater information symmetry, its availability, its patient centricity and ease of understanding, its availability, and greater patient autonomy. Further, technology-assisted non-invasive neurocognitive rehabilitation will require specialists available in larger numbers, is likely to be less expensive, and more widely accessible. Consequently, ethically affirming justice in the delivery of such rehabilitation will be easier than with non-invasive technology.

Ethics of External Technology-Assisted Neurocognitive Rehabilitation

External technologies for assisting neurocognitive rehabilitation include gaming, telerehabilitation, eHealth, communication, and monitoring technologies. Portable, scalable rehabilitation devices featuring clinical intelligence, along with capabilities for remote monitoring and coaching, are key enablers for providing feasible and acceptable distant neurorehabilitation (Lambercy et al., 2021). Remotely deployable digital technologies with remote coaching provide highly individualized training and could strengthen the goal-directed functioning of specific neurocognitive abilities (Loya et al., 2025).

Technological integration in neurocognitive home-rehabilitation enables standardized measures (e.g., response recording), efficiency (i.e., quick and accurate recording), and cost-effectiveness (Charchat-Fichman et al., 2014). Significant improvements in areas of attention, working memory, semantic fluency, emotional functioning, and information processing speed were evident following the use of cognitive telerehabilitation combined with the Transcranial Direct Current Stimulation (tDCS) on a 29-year-old man who had a traumatic brain injury (Eilam-Stock et al., 2021). The need for a well-conceptualized ethical framework of neuro-engineering and rehabilitation technology encompasses user-centric, value-driven design – built on fairness, biomedical ethics, and social responsibility (Ienca et al., 2017).

Care Provider, Caretaker, and Digital Agent Ethics for External Technology

External technologies provide the platform for clinical interactions and support for interventions. They do not play a direct role in either invasive or non-invasive interventions. Hence, their role in assuring beneficence, non-malfeasance, justice, and autonomy (Kelly & Leff, 2023) of an intervention is to assure that the platform fulfils these requirements.

The performance of these external technologies is central to the efficiency and effectiveness of the interventions. These technologies are also the repositories of all the information about the patients, the interventions, and the outcomes. They must be accessible to the care providers, caretakers, and the digital agents as needed. Yet, they must assure the privacy, confidentiality, anonymity, and quality of the information. Further, since many interventions are long-term, these external systems must maintain continuity of support for an extended period.

The ethics challenge of external technology is compounded today by: (a) the large volumes of information, (b) the variety of types of information, (c) the electronification of information, (d) the demand for ready accessibility of information by all the agents, (e) the legal requirements of protection of information, and (f) the exponentially increasing risk of information hacking by mal-intentioned actors.

Conclusion

Technology-assisted neurocognitive rehabilitation is advancing very rapidly propelled by the rapid advances in invasive, non-invasive, and external technologies. However, academic research, government policies, and professional practice guidelines on the ethics of these technologies and their application have not kept pace. There is very little academic research, few policy statements, and only general practice guidelines on the subject. Technologies that assist neurocognitive rehabilitation can deeply affect the body, mind, and spirit of the patients and their caretakers. The ethics of use of these technologies pose unique challenges the answers to which cannot be extended, extrapolated, or generalized from other applications. They require specific focus and attention.

The Ontology of Ethics of Technology-Driven Neurocognitive Rehabilitation is a framework to develop roadmaps for research, policies, and practices on the subject. It can be used to map the states-of-research, -policies, and -practices on the subject. The mapping will help determine the emphases and gaps in the three domains, and the translational gaps between them. Thus, it can be used to highlight the current biases and blind spots and correct them.

Last, the framework is modular. It can be extended to accommodate new technologies, agents, and objectives. Its elements can be refined to study the ethics at a finer level of granularity, or they can be aggregated to study at a higher level. Thus, it can anchor the emergence and evolution of the scientific body of knowledge on the ethics of technology-driven neurocognitive rehabilitation.

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