Article type: Opinion

Home Page URL: https://www.alliedacademies.org/neuroinformatics-and-neuroimaging/

Towards real-time neurofeedback using functional MRI: Algorithms and applications.

Michael Thompson*

Department of Neuroimaging, University of Toronto, Canada.

***Correspondence to:** Michael Thompson, Department of Neuroimaging, University of Toronto, Canada, E-mail: michael.thompson@braininformatics.ca

Received: 03-Jan-2025, Manuscript No. AANN-25-169297; **Editor assigned:** 04-Jan-2025, PreQC No. AANN-25-1692975(PQ); **Reviewed:** 18-Jan-2025, QC No AANN-25-1692975; **Revised:** 21-Jan-2025, Manuscript No. AANN-25-1692975(R); **Published:** 28-Jan-2025, DOI:10.35841/aann -10.2.191

Introduction

Real-time functional magnetic resonance imaging (rt-fMRI) neurofeedback has emerged as a promising technique for enabling individuals to self-regulate brain activity by providing them with immediate feedback derived from their own neural signals. This approach relies on the non-invasive measurement of blood-oxygen-level-dependent (BOLD) signals to monitor changes in brain activity while participants perform cognitive or emotional tasks. By translating these signals into visual or auditory feedback, participants can learn to modulate neural activation patterns associated with specific functions, such as emotion regulation, attention control, or motor imagery. Over the past decade, advances in both imaging technology and computational algorithms have significantly reduced the latency between data acquisition and feedback delivery, making real-time neurofeedback a feasible tool for both research and clinical applications. Its potential spans multiple domains, including neurorehabilitation, mental health interventions, and cognitive enhancement [1].

The core technical challenge of rt-fMRI neurofeedback lies in the development of algorithms that can rapidly and accurately process incoming imaging data. Traditional fMRI analyses are computationally intensive and often require offline processing, making them unsuitable for real-time applications. In rt-fMRI, raw echo-planar imaging (EPI) data must be reconstructed, preprocessed, and analyzed within seconds to provide meaningful feedback. Preprocessing steps typically include motion correction, slice timing correction, and spatial smoothing, all optimized for minimal delay. Signal extraction from targeted regions of interest (ROIs) is then performed, followed by statistical analysis to determine changes in activity relative to baseline. Recent advances in machine learning have enabled the use of multivariate pattern analysis (MVPA) in real-time, allowing for the decoding of complex activation patterns rather than relying solely on mean signal changes. These algorithmic improvements have paved the way for more flexible and adaptive neurofeedback protocols [2].

Applications of rt-fMRI neurofeedback span a wide range of domains in neuroscience and clinical practice. In psychiatric disorders such as depression, participants have been trained to increase activity in brain regions associated with positive affect, such as the ventral striatum, resulting in symptom reduction. In anxiety disorders, neurofeedback has been used to help individuals downregulate amygdala activation, promoting improved emotional control. Neurological rehabilitation also benefits from rt-fMRI, with stroke patients learning to modulate activity in motor-

Citation: Thompson M. Towards real-time neurofeedback using functional MRI: Algorithms and applications. J NeuroInform Neuroimaging. 2025;10(2):191.

related cortical areas to support recovery of movement. Beyond clinical populations, rt-fMRI neurofeedback has been applied in healthy individuals to enhance working memory, attention, and creativity. The adaptability of this approach means that feedback protocols can be tailored to target specific neural circuits relevant to individual therapeutic or cognitive goals [3].

The integration of advanced computational methods is pushing rt-fMRI neurofeedback toward greater precision and personalization. Adaptive algorithms can dynamically adjust feedback thresholds based on participant performance, ensuring that the training remains challenging but achievable. Deep learning models are being explored to predict brain states from partial data, potentially reducing feedback latency even further. Real-time connectivity analyses allow participants to modulate functional coupling between brain regions rather than focusing solely on activation in single ROIs, offering a more network-oriented perspective on brain regulation. Additionally, hybrid approaches that combine rt-fMRI with other modalities such as electroencephalography (EEG) are being developed, capitalizing on the high temporal resolution of EEG and the high spatial resolution of fMRI to deliver richer and more informative feedback [4].

Despite these advances, several challenges remain before rt-fMRI neurofeedback can be widely implemented in clinical practice. The cost and limited availability of MRI scanners restrict access to the technology, making large-scale dissemination difficult. The variability in individual learning ability also poses a challenge, as not all participants are equally able to modulate their brain activity in response to feedback. There is also a need for standardized training protocols and rigorous validation through randomized controlled trials to establish the efficacy of neurofeedback across different conditions. Furthermore, minimizing feedback latency while maintaining accuracy remains an ongoing technical hurdle, especially for whole-brain or connectivity-based feedback. Addressing these issues will be essential for translating rt-fMRI neurofeedback from a promising experimental technique into a robust and reliable therapeutic tool [5].

Conclusion

Real-time fMRI neurofeedback represents a significant step toward empowering individuals to actively influence their own brain activity for therapeutic and cognitive enhancement purposes. Advances in imaging acquisition, rapid preprocessing algorithms, and machine learning-based decoding have brought this technology closer to practical implementation. Its versatility has been demonstrated across a range of clinical and cognitive domains, from aiding recovery after stroke to reducing symptoms in psychiatric disorders. However, technical, logistical, and methodological challenges remain, and ongoing research is focused on improving accessibility, standardization, and personalization of training protocols. As these challenges are addressed, rt-fMRI neurofeedback has the potential to become a transformative tool in neuroscience, mental health care, and human performance optimization.

References

1. Blakely T, Atkinson J, Kvizhinadze G, et al. Patterns of cancer care costs in a country with detailed individual data. Med Care. 2015;53(4):302.
2. Taphoorn MJ, Klein M. Cognitive deficits in adult patients with brain tumours. Lancet Neurol. 2004;3(3):159-68.
3. Langbecker D, Yates P. Primary brain tumor patients’ supportive care needs and multidisciplinary rehabilitation, community and psychosocial support services: Awareness, referral and utilization. J Neurooncol. 2016;127:91-102.
4. Heckel M, Hoser B, Stiel S. Caring for patients with brain tumors compared to patients with non-brain tumors: Experiences and needs of informal caregivers in home care settings. J Psychosoc Oncol. 2018;36(2):189-202.

Citation: Thompson M. Towards real-time neurofeedback using functional MRI: Algorithms and applications. J NeuroInform Neuroimaging. 2025;10(2):191.

5. Sundararajan V, Bohensky MA, Moore G, et al. Mapping the patterns of care, the receipt of palliative care and the site of death for patients with malignant glioma. J Neurooncol. 2014;116:119-26.

Citation: Thompson M. Towards real-time neurofeedback using functional MRI: Algorithms and applications. J NeuroInform Neuroimaging. 2025;10(2):191.