JOURNAL OF INTERNATIONAL CRISIS AND RISK COMMUNICATION RESEARCH
ISSN: 2576-0017
2024, VOL 7, NO S11

Advances in Functional MRI: Applications in Neurological and Psychiatric Disorders

Abdulaziz Mohammad Aleid[1], Misheal Al Dakkan[2], Khalid Aiydh Alharthi[3], Mohammed Khalid Alsahli[4], FATIMAH HAMAD ALSHAMMARI[5], Jawaher yahya zarb[6], Mofleh johar hasan Al-anbar[7], Saad Abdullah Naser Al Daosari[8], Abdullah Saeed Misfer Al Dawsri[9], Jamaan jalal aljameeli[10], abdulrahman hamad alqahtany[11], Joud saud diab ALSHAMMARI[12], Ali Abdullah Alghothimi[13], Bandar Mohammed Qasman[14], SAAD ALI FALEH ALDAWSARI[15]

1. Cluster third Riyadh – AlDiriyah
2. KSMC
3. Cluster third Riyadh – AlDiriyah
4. Cluster third Riyadh – AlDiriyah
5. BCH-Buraidah Central Hospital
6. KSMC
7. Prince sultan cardiac Center Al hasaa
8. Wadi Aldawser General Hospital
9. Wadi Aldawser General Hospital
10. Maternity and Children's Hospital in Hafar Al-Batin
11. Rawda Hospital General View
12. BCH-buraidah central hospital
13. King salman bn abdullaziz hospital
14. Iradah and mental health hospital
15. Wadi aldawser general hospital

ABSTRACT:

Background: Functional neuroimaging has become a cornerstone in the study of brain activity, enabling non-invasive exploration of the brain's structure and function. Techniques such as functional magnetic resonance imaging (fMRI), electroencephalography (EEG), positron emission tomography (PET), and magnetoencephalography (MEG) have offered invaluable insights into the neural mechanisms underlying cognitive, emotional, and behavioral processes. fMRI, in particular, allows for detailed mapping of brain regions through blood oxygenation levels, while EEG captures electrical brain activity with high temporal resolution. These methods have revolutionized the understanding of neurological and psychiatric disorders, offering diagnostic and therapeutic potential.

Aim: This paper explores recent advancements in fMRI and EEG technologies, focusing on their applications in neurological and psychiatric disorders. It aims to provide a comprehensive overview of how these techniques are being applied to unravel the neural underpinnings of disorders such as Alzheimer's disease, Parkinson's disease, schizophrenia, and depression.

Methods: A systematic review of the latest literature on fMRI and EEG advances was conducted, highlighting new methodologies, improved spatial and temporal resolutions, and their combined use in multimodal imaging. Key studies that illustrate the application of these technologies in clinical and research settings were analyzed.

Results: Recent technological advancements in fMRI, such as higher spatial resolution, real-time imaging, and multimodal integration, have expanded the understanding of brain connectivity and dysfunction. EEG developments, including high-density electrode arrays and real-time source localization, have enhanced the precision of tracking neural oscillations and brain connectivity. Together, these innovations have improved the diagnosis and treatment of various neurological and psychiatric conditions.

Conclusion: Advances in fMRI and EEG technologies have significantly enriched the study of brain function, particularly in understanding the pathophysiology of neurological and psychiatric disorders. These techniques have not only enhanced the spatial and temporal resolution of brain imaging but have also paved the way for personalized medicine in treating these conditions.

KEYWORDS: fMRI, EEG, neuroimaging, brain function, neurological disorders, psychiatric disorders, brain connectivity, multimodal imaging, spatial resolution, temporal resolution.

Background:

Neuroimaging serves as a vital technique for evaluating brain functioning by allowing non-invasive access to the anatomical and functional elements of the brain [1,2]. Neuroimaging techniques provide a comprehensive knowledge of the functions of different brain regions in cognitive and behavioral processes, such as perception, attention, memory, language, decision-making, and emotion regulation. Commonly employed neuroimaging techniques in cognitive neuroscience research encompass functional magnetic resonance imaging (fMRI), positron emission tomography (PET), electroencephalography (EEG), and magnetoencephalography (MEG) [4,5]. Each technique provides unique spatial and temporal resolutions, enabling researchers to investigate brain activity across several temporal and spatial dimensions.

fMRI identifies alterations in cerebral blood flow as a marker of neural activity, enabling accurate localization of brain functions and advancing study on processes like attention and working memory. Conversely, PET assesses metabolic alterations, yielding insights into neurochemical activity. EEG and MEG capture electrical and magnetic signals from neural activity, respectively, providing excellent temporal resolution for the examination of brain dynamics. Neuroimaging is utilized to explore mental diseases; for instance, fMRI has been employed to examine the brain pathways in persons with bipolar disorder during emotional activities [6]. Additionally, to examine the impact of pharmacological treatment on alcohol consumption disorder, researchers have performed systematic reviews of fMRI, PET, SPECT, and proton magnetic resonance spectroscopy (H-MRS) to evaluate therapeutic results [7]. Neuroimaging permits the observation of brain activity, mapping of neuronal networks, and research of mechanisms underlying various neurological diseases. These tools have transformed study into cognition, emotion, perception, and other essential elements of brain function by elucidating the dynamic nature of brain processes. Neuroimaging has facilitated substantial progress in comprehending brain architecture, connection, and plasticity. This has facilitated the investigation of the brain correlates associated with behavioral, cognitive, and psychiatric disorders. These strategies bridge the gap between neural activity and mental processes, promoting advances in finding brain-behavior links.

Clinical Utilizations:

In addition to enhancing fundamental neuroscience, neuroimaging is essential in clinical settings. It has changed the diagnosis and treatment of neurological and psychiatric illnesses by enabling biomarker discovery, therapy monitoring, and individualized therapeutic approaches. These methodologies have substantially advanced research on neurodevelopmental disorders, neurodegenerative illnesses, and psychiatric disorders. In summary, neuroimaging has changed the discipline of neuroscience by illuminating the structural and functional dynamics of the brain. Its ability to monitor brain activity and structure has not only improved theoretical comprehension but also advanced hypothesis-driven investigations into the neurological foundations of cognition and behavior.

Noninvasive Functional Neuroimaging Methods:

The importance of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) in examining brain activity and neurological disorders cannot be overstated. These two widely utilized neuroimaging modalities offer complementary insights into brain function. While fMRI measures changes in blood oxygen levels to assess brain activity with excellent spatial resolution, EEG captures the brain's electrical activity, providing superior temporal resolution. Together, these methods allow researchers to integrate spatial and temporal aspects of brain dynamics, offering a holistic understanding of neural processes. Furthermore, their noninvasive nature makes them safe and suitable for repeated use in longitudinal studies, which are essential for tracking brain changes related to neurological disorders and evaluating therapeutic interventions. fMRI and EEG are extensively applied across various domains, including cognitive processing, emotional response, sensory perception, and motor function. These techniques also play a pivotal role in characterizing brain activity and connectivity in disorders such as autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), Alzheimer’s disease (AD), and Parkinson’s disease (PD). The choice of these two modalities as the focal point of discussion stems from their broad applications, noninvasive nature, and significant contribution to advancing the study of brain activity and neurological conditions.

fMRI

Recent Advances in fMRI Technology

Recent technological advancements have enhanced the capabilities of fMRI, enabling more precise investigations of brain function.

- **Higher Spatial Resolution**: Advances in scanner technology now allow imaging of voxels as small as 1 mm, facilitating the study of fine-grained brain structures and activity patterns [8].
- **Real-Time fMRI**: This innovation enables immediate observation of brain activity, supporting applications such as neurofeedback during experiments and therapeutic interventions [9,10,11].
- **Multimodal Imaging**: Integrating fMRI with other techniques, such as EEG or magnetoencephalography (MEG), allows researchers to explore spatial and temporal dynamics simultaneously [12,13].
- **Resting-State fMRI**: This method, which examines brain activity in the absence of tasks, has proven useful for identifying functional connectivity and detecting disorder-related activity changes [14].
- **Ultra-High Field fMRI**: Operating at 7 Tesla or higher, these scanners offer enhanced sensitivity and spatial resolution, providing deeper insights into neural activity [15].

Applications of fMRI in Studying Brain Function

fMRI has revolutionized the understanding of brain function with applications such as:

- **Mapping Brain Activity**: By identifying active brain regions during specific tasks or stimuli, fMRI facilitates the mapping of functional networks and understanding of interregional connectivity [4].
- **Cognitive Process Exploration**: Studies using fMRI have shed light on how the brain processes information related to perception, memory, language, and decision-making [16].
- **Advancements in Connectivity Analysis**: Techniques like multiband imaging and graph theory enhance the study of functional connectivity, enabling insights into cognitive processes and disorder mechanisms.
- **Neurological Disorder Research**: fMRI is instrumental in investigating conditions such as AD, PD, schizophrenia, and depression, uncovering underlying mechanisms and aiding diagnosis and treatment [17,18].

- **Therapeutic Development**: By pinpointing disorder-specific brain regions, fMRI has guided interventions like deep brain stimulation for PD and depression [19].

Recent Advances in Neuroimaging Techniques and Their Impact

Progress in neuroimaging has deepened the precision and scope of brain research:

- **High-Resolution Structural MRI**: Provides sub-millimeter imaging of the cortex, enabling refined brain mapping and the discovery of new regions [20].

- **Diffusion-Weighted MRI**: Offers insights into white matter connections and their links to neurological disorders [21].

- **Resting-State fMRI**: Explores intrinsic brain activity and functional networks, contributing to the understanding of cognition and behavior [22].

- **Multimodal Neuroimaging**: Combining fMRI with modalities like EEG or PET delivers comprehensive perspectives on neural activity [23,24].

- **Ultrafast fMRI**: Techniques such as multiband fMRI allow faster data acquisition, capturing dynamic neural changes with enhanced accuracy [25].

These advances have significantly enriched cognitive neuroscience, offering new methodologies for studying brain structure and function, understanding brain disorders, and paving the way for innovative treatments.

fMRI Data Analysis Techniques and Algorithms

Numerous specialized techniques and algorithms are employed in the analysis of fMRI data to investigate brain functionality and neurological disorders.

- **Seed-based Functional Connectivity:** This approach entails selecting a specific seed region of interest and computing the correlations between the seed region's time series and all other brain voxels. It enables researchers to examine functional connectivity between the seed region and other areas of the brain, uncovering networks and connectivity patterns related to distinct brain functions or disorders.
- **Independent Component Analysis (ICA):** As a data-driven technique, ICA decomposes fMRI data into spatially independent components that represent distinct functional networks. It is particularly effective for identifying resting-state networks, such as the default mode network, and analyzing their alterations in various diseases.
- **Graph-Theoretic Analysis:** By applying graph theory, researchers can describe and quantify the topological properties of brain networks derived from fMRI data. Metrics such as node degree, clustering coefficient, and betweenness centrality facilitate the evaluation of network organization and identification of disease-related network-level changes.
- **Machine Learning Approaches:** Machine learning techniques, including support vector machines (SVM), random forests, and deep learning, have been applied to fMRI data for classifying brain states, predicting clinical outcomes, and identifying biomarkers. These algorithms effectively extract meaningful patterns from fMRI data, enabling precise classification and prediction of neurological conditions.

- **Multivariate Pattern Analysis (MVPA):** MVPA trains machine learning algorithms on fMRI data to decode or differentiate mental states or stimuli. This technique is instrumental in analyzing detailed patterns of brain activity associated with specific cognitive processes or disorders and has been widely utilized in cognitive neuroscience and clinical research.

The field of fMRI data analysis continues to evolve, as researchers develop innovative methods to extract valuable insights from complex brain imaging data, advancing our understanding of brain function and neurological disorders.

Recent Advances in fMRI Technology

The continuous advancements in fMRI technology have substantially enhanced spatial and temporal resolution, improving the precision and specificity of brain activity measurements.

- **High-field MRI:** Utilizing magnetic field strengths such as 3 Tesla (3T) or 7 Tesla (7T) enhances spatial resolution, allowing researchers to discern small brain structures and finer details for more accurate localization of brain activity.
- **Multi-echo Imaging:** This technique acquires multiple echoes at various time points, enabling the separation of the blood oxygen level-dependent (BOLD) signal from other sources of signal variation. This improves the specificity of neural activity measurements.
- **Parallel Imaging:** Techniques like Sensitivity Encoding (SENSE) and Generalized Autocalibration Partially Parallel Acquisition (GRAPPA) utilize multiple receive coils to accelerate image acquisition, enhancing temporal resolution and enabling more precise tracking of dynamic brain activity.
- **Simultaneous Multi-Slice (SMS) Imaging:** SMS imaging captures multiple brain slices simultaneously, increasing coverage while reducing acquisition time. This facilitates faster whole-brain imaging with improved temporal resolution, critical for studying rapid brain processes.
- **Ultrafast Echo Planar Imaging (EPI):** Recent advancements in EPI, such as multiband imaging and blipped-CAIPI, have significantly reduced acquisition times while maintaining image quality, enabling higher temporal resolution and better detection of transient neural events.

Recent Advances in EEG Technology

Electroencephalography (EEG), a non-invasive technique for measuring the brain's electrical activity [26–29], has also benefited from technological advancements.

- **High-density Electrode Arrays:** Modern EEG systems incorporate hundreds of electrodes, allowing for more accurate localization of brain activity and detailed mapping of neural dynamics [30].
- **Real-time Source Localization:** This innovation facilitates the real-time identification of the strength and location of brain activity, which is particularly useful for neurofeedback and brain-computer interface applications [31].
- **Wearable EEG Technology:** Portable EEG systems now enable brain activity monitoring in non-laboratory environments, with promising applications in clinical settings to monitor neurological disorders [32].

- **Integration with Other Neuroimaging Techniques:** EEG can be combined with modalities like fMRI to provide complementary insights into both spatial and temporal aspects of brain activity [33,34].

Applications of EEG in Brain Function and Neural Oscillations

EEG serves as a robust tool for exploring brain function and neural oscillations [35]. Its applications include:

1. **Mapping Brain Activity:** EEG maps the timing and localization of brain activity linked to cognitive processes, offering insights into their underlying neural mechanisms.

2. **Studying Neural Oscillations:** EEG examines rhythmic patterns of brain activity, known as neural oscillations, which are critical for brain information processing [36].

3. **Investigating Brain Connectivity:** EEG assesses functional and effective connectivity between brain regions, shedding light on neural networks governing cognition and behavior [37,38].

4. **Studying Brain Development:** EEG tracks changes in neural oscillations and brain function throughout development, providing insights into cognitive maturation [39].

Overall, EEG technology continues to offer versatile and valuable approaches for understanding neural mechanisms across basic and applied research contexts.

EEG Signal Processing Techniques

Processing EEG signals is vital for extracting meaningful information and analyzing neural oscillations.

- **Preprocessing:** This step removes artifacts and improves data quality, employing filtering (e.g., noise removal), artifact elimination (e.g., independent component analysis), and baseline correction.
- **Power Spectrum Analysis:** Using methods like the Fast Fourier Transform (FFT), this analysis reveals the distribution of power across frequency bands, offering insights into oscillatory activity linked to cognitive states or pathologies.
- **Event-Related Potential (ERP):** ERP analysis isolates brain responses time-locked to specific events, identifying components such as P300 or N400 for high temporal precision in cognitive studies.
- **Time-Frequency Analysis:** Techniques like the short-time Fourier transform or wavelet transform analyze spectral content over time, identifying transient or task-specific modulations in neural activity.
- **Connectivity Analysis:** Methods such as coherence or phase synchrony evaluate functional connectivity, revealing the dynamics and interactions between brain regions.
- **Source Localization:** Techniques such as dipole fitting and distributed source modeling pinpoint neural generators, enabling precise mapping of brain activity.

These methods significantly advance our ability to decode and interpret brain function, enhancing the breadth of neuroscience research.

Recent Innovations in EEG Technology: Expanding Its Utility in Brain Activity and Disease Studies

High-Density EEG and Advanced Electrode Design

High-Density EEG Systems: Traditional EEG systems, constrained by a limited number of electrodes, provide sparse spatial scalp coverage. Recent technological advancements have introduced high-density EEG systems with electrode configurations reaching 128, 256, or even 512 channels. These systems facilitate enhanced spatial mapping and more precise localization of neural activity sources.

Flexible Dry Electrodes: Unlike traditional electrodes that rely on conductive gels or pastes, dry and flexible electrodes have emerged, offering greater comfort and ease of placement. These innovative designs maintain high signal quality, reduce preparation time, and are particularly advantageous for long-term monitoring and clinical applications.

Signal Processing and Source Localization

Advanced Source Localization: New algorithms leveraging high-density configurations and sophisticated mathematical models have significantly improved the precision of estimating neural source locations from EEG signals.

Connectivity Analysis: Drawing parallels with functional MRI (fMRI), EEG data can now be employed to analyze functional connectivity across brain regions. Techniques such as coherence, phase synchrony, and graph theory enable the exploration of inter-regional communication and coordination.

Multimodal Integration

fMRI-EEG Fusion: Integrating EEG with fMRI provides simultaneous measurements of electrical activity and hemodynamic responses, offering complementary insights into brain functionality. This approach enables the correlation of EEG-detected neural oscillations with the network structures identified via fMRI.

EEG-TMS Integration: Combining EEG with Transcranial Magnetic Stimulation (TMS), a non-invasive brain stimulation method, allows researchers to observe the direct effects of TMS on brain activity and explore its therapeutic and cognitive implications.

Wearable and Mobile EEG

The miniaturization of technology and advancements in wireless systems have led to wearable and mobile EEG devices. These lightweight, portable systems enable ecologically valid measurements of brain activity in naturalistic and diverse environments. These advancements have broadened the applications of EEG technology, enhancing its spatial resolution, signal quality, and ability to investigate neural dynamics and connectivity. As a result, these developments hold significant promise for diagnosing, monitoring, and treating neurological and psychiatric disorders.

Limitations and Challenges of fMRI and EEG Technologies

Despite their utility, fMRI and EEG technologies face specific limitations that influence their applicability and reliability.

Spatial Resolution

While fMRI offers high spatial resolution, it struggles to resolve fine-scale neural activity at the neuronal or cerebellar level, with its resolution typically in millimeters. EEG, on the other hand, suffers from poor spatial resolution, as its signals represent aggregated activity from extensive brain tissue, complicating the pinpointing of precise sources.

Temporal Resolution

fMRI, though spatially detailed, has limited temporal resolution due to the inherent delay of several seconds in the blood-oxygen-level-dependent (BOLD) signal. In contrast, EEG excels in capturing millisecond-level neural dynamics, though it is less adept at detecting slower or sustained neural processes.

Signal-to-Noise Ratio (SNR)

fMRI measurements are susceptible to noise from motion artifacts, physiological variations, and scanner distortions, reducing reliability. Similarly, EEG signals are weak and prone to contamination by muscle movements, ocular artifacts, and ambient electrical noise, complicating data interpretation.

Interpretation Challenges

Interpreting fMRI results necessitates careful consideration of the BOLD signal, an indirect neural activity measure influenced by vascular and metabolic factors. Similarly, EEG data analysis faces difficulties in accurately localizing neural sources due to overlapping signals and volumetric conduction effects, which obscure the attribution of activity to specific brain regions. Despite these challenges, fMRI and EEG remain indispensable tools for exploring brain function and neurological disorders. With meticulous methodological approaches, these technologies provide critical insights into neural mechanisms, significantly advancing our understanding of brain activity and associated conditions.

Diffusion Tensor Imaging (DTI)

Recent Technological Developments in DTI

Diffusion Tensor Imaging (DTI) is a specialized MRI technique used to visualize white matter tracts in the brain [40]. Recent advances include:

1. **High Angular Resolution Diffusion Imaging (HARDI):** This approach refines traditional DTI by utilizing higher angular resolution, allowing for detailed visualization of intricate white matter structures [41]. It captures water diffusion directionality more accurately, enabling enhanced tractography and improved mapping of white matter connectivity.

2. Accelerated Imaging Techniques: Advanced methods, including compressed sensing and parallel imaging, substantially decrease scan times while maintaining image quality [42]. These innovations are particularly valuable for clinical applications, improving patient comfort and minimizing motion artifacts.

These advancements bolster our ability to study white matter structure and connectivity, with significant implications for diagnosing and treating neurological disorders.

Applications of DTI in Studying Brain Connectivity and White Matter Tracts

DTI is a crucial tool for investigating brain connectivity and white matter tracts [43]. Key applications include:

- **Mapping White Matter Tracts:** DTI enables the visualization and mapping of white matter tracts, such as the corpus callosum and corticospinal tract, allowing researchers to examine connectivity between brain regions [44].

- **Identifying Neurological Changes:** Structural alterations in white matter associated with conditions like Alzheimer's disease, multiple sclerosis, and traumatic brain injury can be detected using DTI [45,46,47]. This aids in diagnosis, monitoring, and treatment development.

- **Studying Brain Development:** By analyzing changes in white matter during development, DTI provides insights into the evolution of cognitive functions, including language and memory [43].

- **Exploring Brain Plasticity:** DTI is instrumental in investigating changes in white matter connectivity linked to learning and training [48], offering potential applications in rehabilitation.

Advances in DTI Analysis Methods

Recent developments in DTI analysis have enhanced its accuracy and utility. For instance:

- **HARDI Techniques:** Advanced methods, such as Diffusion Spectral Imaging and High Definition Fiber Tracking, improve the resolution of intersecting fibers, leading to more precise tractography.

- **Multi-Shell and Multi-Tissue Modeling:** These approaches separate isotropic and anisotropic diffusion, offering detailed microstructural insights.

- **Advanced Tractography Algorithms:** Techniques like probabilistic modeling and constrained spherical deconvolution improve the reliability of fiber tracking.

These innovations enable refined mapping of brain networks, quantitative assessments of white matter properties, and deeper insights into brain function in health and disease.

Applications of DTI:

Mapping White Matter Tracts: DTI enables researchers to map the trajectories of major white matter tracts in the brain, providing valuable insights into anatomical connections between different brain regions.

Studying Brain Connectivity: By quantifying the direction and magnitude of water diffusion, DTI estimates diffusion tensor metrics such as fractional anisotropy (FA) and mean diffusivity (MD). These metrics are instrumental in studying the integrity and connectivity of white matter pathways.

Understanding Neurological Diseases: DTI has been extensively used to examine altered white matter connectivity in neurological and psychiatric disorders, including schizophrenia, Alzheimer's disease, multiple sclerosis, and traumatic brain injury. It helps identify specific white matter abnormalities associated with these conditions and understand their impact on brain function.

High Angular Resolution Diffusion Imaging (HARDI): HARDI techniques, such as q-sphere and diffusion spectral imaging, enhance DTI accuracy and resolution by modeling complex fiber orientations and overcoming challenges posed by intersecting fibers.

Tractography and Connectivity Analysis: Advanced tractography algorithms accurately reconstruct white matter pathways. Connectivity analysis techniques, such as graph theory, allow researchers to explore structural brain networks and investigate their alterations in neurological diseases.

Applications of TES: Non-Invasive Brain Stimulation

Investigating Brain Function

TES techniques, such as transcranial direct current stimulation (tDCS) and transcranial alternating current stimulation (tACS), provide non-invasive methods to modulate brain activity and study functional connectivity. TES enables researchers to probe causal relationships between brain regions, investigate the active contribution of brain networks, and study the effects of targeted stimulation on behavior, cognition, and perception.

Potential Therapeutic Applications

- **Schizophrenia:** Studies suggest that TES, particularly tDCS, can serve as an adjunctive treatment for schizophrenia by modulating cortical excitability and network connectivity, potentially improving cognitive function and reducing symptoms.

- **Chronic Pain:** TES techniques, such as transcutaneous electrical nerve stimulation (TENS), offer non-invasive pain management strategies by targeting pain-related brain regions to modulate pain perception.

Targeted Stimulation

Advancements in TES technology enable precise targeting of brain regions or networks. High-resolution neuroimaging techniques like fMRI or EEG, when combined with TES, enhance electrode placement accuracy and optimize stimulation protocols.

Limitations, Challenges, and Potential Future Directions

Limitations and Challenges of DTI

- **Tissue Complexity:** Simplified water diffusion models may not fully represent the microstructural properties of brain tissue, challenging accurate quantification.

- **Fiber Crossings and Orientation Dispersion:** Complex fiber configurations can lead to inaccurate reconstruction of white matter tracts.

- **Sensitivity to Noise and Artifacts:** Motion artifacts and susceptibility distortions degrade image quality, affecting the reliability of diffusion metrics.

- **Spatial Resolution:** Achieving high spatial resolution is constrained by long acquisition times and image distortions, limiting the detection of small-scale structures.

Future Directions and Improvements for DTI

- **Advanced Diffusion Models:** Techniques like HARDI and Diffusion Kurtosis Imaging (DKI) offer better representation of complex fiber orientations.

- **Multimodal Integration:** Combining DTI with modalities such as fMRI or EEG provides a comprehensive understanding of structural and functional connectivity.

- **Enhanced Image Acquisition:** Higher field strengths, parallel imaging, and motion correction methods can improve spatial resolution and image quality.

- **Advanced Analytical Methods:** Refined algorithms and network-based methods enhance tractography accuracy and connectivity estimation.

Limitations and Challenges of TES

- **Spatial Localization and Individual Differences:** Anatomical variation, skull conductivity, and electrode placement variability affect electric field distribution.

- **Limited Mechanistic Understanding:** The exact neurobiological mechanisms of TES remain unclear, requiring further research to optimize parameters.

- **Inter- and Within-Subject Variability:** Variability in responses to TES complicates standardized protocol development and outcome prediction.

- **Potential Side Effects:** While TES is generally safe, minor side effects such as scalp irritation occur, and the long-term effects need further investigation.

Future Directions and Improvements in TES

- **Personalized Approaches:** Brain mapping using structural or functional connectivity data can guide personalized protocols and improve electrode placement.

- **Closed-Loop and Adaptive Stimulation:** Integrating real-time brain activity monitoring with stimulation adjustments ensures optimized outcomes.

- **Multimodal Integration:** Combining TES with fMRI or EEG provides feedback on brain activity, improving stimulation accuracy and targeting.
- **Improved Electrode Design:** Advanced, flexible electrode designs enhance electrical contact, reduce discomfort, and improve effectiveness.

Neuroimaging and Brain Functions

Neuroimaging Studies on Neurodevelopmental Disorders, Such as ASD and ADHD

Autism Spectrum Disorder (ASD) is a heterogeneous illness characterized by a diverse array of symptoms and varying degrees of severity, resulting in its designation as a "spectrum" disorder. Studies have repeatedly shown that individuals with ASD display atypical brain architecture and functioning, especially in areas related to speech, social interaction, and sensory processing [68,69]. These structural and functional anomalies can impair the brain networks essential for learning, memory, and emotional regulation. Autism Spectrum Disorder (ASD) exhibits a greater frequency in boys, impacting roughly 1 in 54 children in the United States. While the exact etiology of ASD is still unknown and no remedy is available, neuroimaging research has greatly enhanced our comprehension of the cerebral pathways implicated in this neurodevelopmental condition [71,72,73]. Research has discovered variances in the size and shape of the amygdala, crucial for emotional processing, as well as differences in the connectivity and structure of the prefrontal cortex, which is essential for social cognition and executive processes [77,78,79,80]. Attention Deficit Hyperactivity disease (ADHD), a common neurodevelopmental disease, affects roughly 6–9% of children and 5% of adults worldwide [81,82]. Neuroimaging research indicates significant structural and functional disparities in the brains of individuals with ADHD relative to those without the condition [83]. Abnormalities have been detected in the prefrontal cortex, basal ganglia, and cerebellum, regions associated with attention, motivation, and motor control [84,85]. The symptomatology of ADHD is marked by challenges in attention, impulsivity, and activity regulation, which can fluctuate in severity and profoundly impact academic, social, and vocational performance. Neuroimaging studies have revealed abnormalities in the dimensions of the basal ganglia, integral to motor control and reward processing [86,87], alongside modifications in the activity and connectivity of the prefrontal cortex, essential for attentional control and executive processes [88,89]. These findings offer significant insights into the neurological underpinnings underlying ADHD and guide prospective therapies.

TES in ASD

Transcranial Electrical Stimulation (TES) has lately garnered interest as a potential treatment intervention for Autism Spectrum Disorder (ASD) [90,91,92,93,94,95,96,97,98]. Transcranial Direct Current Stimulation (tDCS), a kind of TES, utilizes mild electrical currents to influence cortical excitability and has surfaced as a prospective intervention for ASD [90,93,94,95,97,99]. Investigations into the effects of tDCS on patients with ASD have evaluated its influence on cerebral metabolism, symptom alleviation, social cognition, social skills, and modulation of EEG activity. Several studies have indicated favorable results, suggesting that tDCS may provide advantages in addressing specific ASD symptoms, notably those associated with social communication impairments. Despite the evidence being preliminary, tDCS demonstrates potential as an additional therapy for ASD.

TES in ADHD

The utilization of TES, namely tDCS, has been examined as a therapeutic intervention for ADHD. tDCS has demonstrated potential in enhancing attention and diminishing hyperactivity in children with ADHD by altering cortical excitability [100,101,102,103,104,105]. Numerous studies have demonstrated the beneficial impacts of tDCS on cognitive functions, including cognitive control, inhibitory control, attentional set-shifting, and working memory, indicate that tDCS may effectively mitigate ADHD symptoms, improving cognitive and behavioral outcomes. Although additional study is necessary, the existing data endorses tDCS as an effective intervention for controlling ADHD.

Neuroimaging Studies on Neurological Disorders, Such as AD and PD

Alzheimer’s Disease (AD), a progressive neurological disorder, is the predominant cause of dementia, representing 60–80% of global dementia cases [106]. The defining characteristics of Alzheimer's disease (AD) include the aggregation of amyloid plaques and tau tangles, which impair cellular communication and lead to neuronal degeneration [107,108,109]. Initial symptoms generally encompass memory impairment, especially regarding recent information, and as the condition progresses, individuals encounter deficiencies in language, spatial cognition, problem-solving abilities, and daily activities. Mood, behavior, and personality alterations are also prevalent. Diagnosis generally entails neurological assessments, cognitive evaluations, and imaging techniques such as MRI scans [111]. Although a cure is unavailable, treatments focus on symptom management and the deceleration of disease development. Neuroimaging has been essential in revealing the structural and functional changes in the brains of Alzheimer's disease patients. Research has shown substantial decreases in brain volume, especially in the hippocampus, a region critical for memory, as well as modified connections among brain regions and alterations in glucose metabolism. Parkinson’s Disease (PD) is a common neurological condition, impacting over 1% of the population over 60 years of age [118]. Initial manifestations of Parkinson's Disease encompass tremors, rigidity, and bradykinesia; as the condition advances, individuals encounter motor deficits, notably in balance and coordination. Non-motor symptoms, including depression, anxiety, and sleep difficulties, also manifest. Diagnosing Parkinson's Disease necessitates thorough evaluations, encompassing neurological assessments, imaging modalities like MRI scans, and the evaluation of both motor and non-motor symptoms [120]. Although Parkinson's disease is presently incurable, treatment emphasizes the management of symptoms. Neuroimaging studies have been pivotal in revealing significant alterations in Parkinson's disease, including diminished dopaminergic activity resulting from the degeneration of dopaminergic neurons, as well as changes in the size and connectivity of brain regions associated with movement regulation, notably the basal ganglia and motor cortex. These discoveries are crucial for diagnosing, monitoring, and formulating novel therapy strategies for PD.

TES in AD

The therapeutic efficacy of transcranial electrical stimulation, namely transcranial direct current stimulation, has been investigated as an intervention for cognitive deterioration and memory impairments in Alzheimer's disease. Numerous research suggest that tDCS may augment cognitive performance and memory in persons with Alzheimer's disease, hence enhancing daily living activities and general functioning [125,126]. Studies utilizing tDCS have specifically seen beneficial effects on cognitive functions and memory in patients with Alzheimer's disease [127,128,129,130]. Although these data are preliminary, they indicate that tDCS may be a useful remedy for cognitive deficits in people with Alzheimer's disease.

Conclusion:

The integration of advanced functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) technologies has profoundly transformed the field of neuroscience. These non-invasive techniques have allowed for precise measurements of brain activity, offering new insights into both normal and pathological brain function. Recent advancements in fMRI technology, such as higher spatial resolution, real-time imaging, and multimodal capabilities, have significantly enhanced our ability to map brain activity with exceptional accuracy. For instance, the ability to capture neural activity at sub-millimeter resolutions and the introduction of ultrahigh field scanners (e.g., 7T) has facilitated the identification of fine-grained brain structures and networks. Furthermore, the integration of fMRI with EEG and other neuroimaging methods has enriched the study of brain connectivity, providing a holistic view of brain dynamics that was previously unattainable. These advances have critical implications for the study and treatment of neurological disorders such as Alzheimer's, Parkinson's, and schizophrenia, as they allow for more precise localization of dysfunction and offer insights into the mechanisms underlying these conditions. EEG, with its high temporal resolution, continues to be a vital tool for tracking rapid brain processes. Innovations such as high-density electrode arrays, real-time source localization, and the development of wearable EEG systems have expanded the potential for EEG to be applied in both clinical and research settings. The ability to assess neural oscillations, brain connectivity, and event-related potentials with unprecedented precision has provided valuable data for understanding cognitive processes and psychiatric disorders like depression and attention deficit hyperactivity disorder (ADHD). In clinical settings, these neuroimaging advancements have opened the door to more personalized approaches to diagnosis and treatment. fMRI and EEG are increasingly being utilized to guide therapeutic interventions such as deep brain stimulation and neurofeedback, offering tailored solutions to patients based on their specific neural activity patterns. Additionally, the application of these techniques in neurodevelopmental and neurodegenerative disorders has contributed to the identification of biomarkers and the development of targeted treatments. In conclusion, the continuous evolution of fMRI and EEG technologies has significantly advanced the understanding of brain function. Their integration into both research and clinical applications has provided deeper insights into the neural bases of cognition, emotion, and behavior, offering hope for improved diagnostics and interventions for neurological and psychiatric disorders.

References:

Litwinczuk, M.C.; Trujillo-Barreto, N.; Muhlert, N.; Cloutman, L.; Woollams, A. Relating Cognition to both Brain Structure and Function: A Systematic Review of Methods. *Brain Connect.* **2023**, *13*, 120–132.

Morita, T.; Asada, M.; Naito, E. Contribution of Neuroimaging Studies to Understanding Development of Human Cognitive Brain Functions. *Front. Hum. Neurosci.* **2016**, *10*, 464.

Elam, J.S.; Glasser, M.F.; Harms, M.P.; Sotiropoulos, S.N.; Andersson, J.L.R.; Burgess, G.C.; Curtiss, S.W.; Oostenveld, R.; Larson-Prior, L.J.; Schoffelen, J.M.; et al. The Human Connectome Project: A retrospective. *Neuroimage* **2021**, *244*, 118543.

Ebrahimzadeh, E.; Saharkhiz, S.; Rajabion, L.; Oskouei, H.B.; Seraji, M.; Fayaz, F.; Saliminia, S.; Sadjadi, S.M.; Soltanian-Zadeh, H. Simultaneous electroencephalography-functional magnetic resonance imaging for assessment of human brain function. *Front. Syst. Neurosci.* **2022**, *16*, 934266.

Bringas-Vega, M.L.; Michel, C.M.; Saxena, S.; White, T.; Valdes-Sosa, P.A. Neuroimaging and global health. *Neuroimage* **2022**, *260*, 119458.

Sepede, G.; De Berardis, D.; Campanella, D.; Perrucci, M.G.; Ferretti, A.; Salerno, R.M.; Di Giannantonio, M.; Romani, G.L.; Gambi, F. Neural correlates of negative emotion processing in bipolar disorder. *Prog. Neuropsychopharmacol. Biol. Psychiatry* **2015**, *60*, 1–10

Florence, L.; Lassi, D.L.S.; Kortas, G.T.; Lima, D.R.; de Azevedo-Marques Perico, C.; Andrade, A.G.; Torales, J.; Ventriglio, A.; De Berardis, D.; De Aquino, J.P.; et al. Brain Correlates of the Alcohol Use Disorder Pharmacotherapy Response: A Systematic Review of Neuroimaging Studies. *Brain Sci.* **2022**, *12*, 386.

Bollmann, S.; Barth, M. New acquisition techniques and their prospects for the achievable resolution of fMRI. *Prog. Neurobiol.* **2021**, *207*, 101936.

Heunis, S.; Lamerichs, R.; Zinger, S.; Caballero-Gaudes, C.; Jansen, J.F.A.; Aldenkamp, B.; Breeuwer, M. Quality and denoising in real-time functional magnetic resonance imaging neurofeedback: A methods review. *Hum. Brain Mapp.* **2020**, *41*, 3439–3467.

Humpston, C.; Garrison, J.; Orlov, N.; Aleman, A.; Jardri, R.; Fernyhough, C.; Allen, P. Real-Time Functional Magnetic Resonance Imaging Neurofeedback for the Relief of Distressing Auditory-Verbal Hallucinations: Methodological and Empirical Advances. *Schizophr. Bull.* **2020**, *46*, 1409–1417.

Rana, M.; Ruiz, S.; Corzo, A.S.; Muehleck, A.; Eck, S.; Salinas, C.; Zamorano, F.; Silva, C.; Rea, M.; Batra, A.; et al. Use of Real-Time Functional Magnetic Resonance Imaging-Based Neurofeedback to Downregulate Insular Cortex in Nicotine-Addicted Smokers. *J. Vis. Exp.* **2020**, *160*, e59441.

Gross, J. Magnetoencephalography in Cognitive Neuroscience: A Primer. *Neuron* **2019**, *104*, 189–204.

Lin, F.H.; Witzel, T.; Hamalainen, M.S.; Nummenmaa, A. Combining Noninvasive Electromagnetic and Hemodynamic Measures of Human Brain Activity. In *Brain and Human Body Modeling 2020: Computational Human Models Presented at EMBC 2019 and* *the BRAIN Initiative(R) 2019 Meeting*; Makarov, S.N., Noetscher, G.M., Nummenmaa, A., Eds.; Springer International Publishing: Cham, Switzerland, 2021; pp. 179–193.

Lv, H.; Wang, Z.; Tong, E.; Williams, L.M.; Zaharchuk, G.; Zeineh, M.; Goldstein-Piekarski, A.N.; Ball, T.M.; Liao, C.; Wintermark, M. Resting-State Functional MRI: Everything That Nonexperts Have Always Wanted to Know. *AJNR Am. J. Neuroradiol.* **2018**, *39*, 1390–1399.

Viessmann, O.; Polimeni, J.R. High-resolution fMRI at 7 Tesla: Challenges, promises and recent developments for individual-focused fMRI studies. *Curr. Opin. Behav. Sci.* **2021**, *40*, 96–104.

Yen, C.; Chiang, M.C. Examining the effect of online advertisement cues on human responses using eye-tracking, EEG, and MRI. *Behav. Brain Res.* **2021**, *402*, 113128.

Shen, J.; Xu, C. Analysis of Brain Activity Changes in Patients with Parkinson's Disease Based on Resting-State Functional Magnetic Resonance Imaging. *J. Health Eng.* **2022**, *2022*, 8561351.

Spinosa, V.; Brattico, E.; Campo, F.; Logroscino, G. A systematic review on resting state functional connectivity in patients with neurodegenerative disease and hallucinations. *Neuroimage Clin.* **2022**, *35*, 103112.

Boutet, A.; Madhavan, R.; Elias, G.J.B.; Joel, S.E.; Gramer, R.; Ranjan, M.; Paramanandam, V.; Xu, D.; Germann, J.; Loh, A.; et al. Predicting optimal deep brain stimulation parameters for Parkinson's disease using functional MRI and machine learning. *Nat. Commun.* **2021**, *12*, 3043.

Zeng, C.; Chen, Z.; Yang, H.; Fan, Y.; Fei, L.; Chen, X.; Zhang, M. Advanced high resolution three-dimensional imaging to visualize the cerebral neurovascular network in stroke. *Int. J. Biol. Sci.* **2022**, *18*, 552–571.

Giraldo, D.L.; Smith, R.E.; Struyfs, H.; Niemantsverdriet, E.; De Roeck, E.; Bjerke, M.; Engelborghs, S.; Romero, E.; Sijbers, J.; Jeurissen, B. Investigating Tissue-Specific Abnormalities in Alzheimer's Disease with Multi-Shell Diffusion MRI. *J. Alzheimers Dis.* **2022**, *90*, 1771–1791.

Raimondo, L.; Oliveira, L.A.F.; Heij, J.; Priovoulos, N.; Kundu, P.; Leoni, R.F.; van der Zwaag, W. Advances in resting state fMRI acquisitions for functional connectomics. *Neuroimage* **2021**, *243*, 118503.

Warbrick, T. Simultaneous EEG-fMRI: What Have We Learned and What Does the Future Hold? *Sensors* **2022**, *22*, 2262.

Fernandez-Iriondo, I.; Jimenez-Marin, A.; Sierra, B.; Aginako, N.; Bonifazi, P.; Cortes, J.M. Brain Mapping of Behavioral Domains Using Multi-Scale Networks and Canonical Correlation Analysis. *Front. Neurosci.* **2022**, *16*, 889725.

Vanstrum, E.B.; Borzage, M.T.; Ha, J.; Chu, J.; Upreti, M.; Moats, R.A.; Lai, L.M.; Chiarelli, P.A. Development of an ultrafast brain MR neuronavigation protocol for ventricular shunt placement. *J. Neurosurg.* **2023**, *138*, 367–373.

Chiang, M.-C.; Yen, C.; Chen, H.-L. Does Age Matter? Using Neuroscience Approaches to Understand Consumers’ Behavior towards Purchasing the Sustainable Product Online. *Sustainability* **2022**, *14*, 11352.

Yen, C.; Chiang, M.-C. Trust me, if you can: A study on the factors that influence consumers' purchase intention triggered by chatbots based on brain image evidence and self-reported assessments. *Behav. Inf. Technol.* **2021**, *40*, 1177–1194.

Omejc, N.; Peskar, M.; Miladinovic, A.; Kavcic, V.; Dzeroski, S.; Marusic, U. On the Influence of Aging on Classification Performance in the Visual EEG Oddball Paradigm Using Statistical and Temporal Features. *Life* **2023**, *13*, 391.

Vilou, I.; Varka, A.; Parisis, D.; Afrantou, T.; Ioannidis, P. EEG-Neurofeedback as a Potential Therapeutic Approach for Cognitive Deficits in Patients with Dementia, Multiple Sclerosis, Stroke and Traumatic Brain Injury. *Life* **2023**, *13*, 365.

Soler, A.; Moctezuma, L.A.; Giraldo, E.; Molinas, M. Automated methodology for optimal selection of minimum electrode subsets for accurate EEG source estimation based on Genetic Algorithm optimization. *Sci. Rep.* **2022**, *12*, 11221.

Munoz-Gutierrez, P.A.; Giraldo, E.; Bueno-Lopez, M.; Molinas, M. Localization of Active Brain Sources From EEG Signals Using Empirical Mode Decomposition: A Comparative Study. *Front. Integr. Neurosci.* **2018**, *12*, 55.

Casson, A.J. Wearable EEG and beyond. *Biomed. Eng. Lett.* **2019**, *9*, 53–71.

Lioi, G.; Cury, C.; Perronnet, L.; Mano, M.; Bannier, E.; Lecuyer, A.; Barillot, C. Simultaneous EEG-fMRI during a neurofeedback task, a brain imaging dataset for multimodal data integration. *Sci. Data* **2020**, *7*, 173.

Poudel, G.R.; Jones, R.D. Multimodal Neuroimaging with Simultaneous fMRI and EEG. In *Handbook of Neuroengineering*; Thakor, N.V., Ed.; Springer: Singapore, 2020; pp. 1–23.

Cohen, M.X. Where Does EEG Come From and What Does It Mean? *Trends Neurosci.* **2017**, *40*, 208–218.

Jee, S. Brain Oscillations and Their Implications for Neurorehabilitation. *Brain Neurorehabilit.* **2021**, *14*, e7.

Cao, J.; Zhao, Y.; Shan, X.; Wei, H.L.; Guo, Y.; Chen, L.; Erkoyuncu, J.A.; Sarrigiannis, P.G. Brain functional and effective connectivity based on electroencephalography recordings: A review. *Hum. Brain Mapp.* **2022**, *43*, 860–879.

Chiarion, G.; Sparacino, L.; Antonacci, Y.; Faes, L.; Mesin, L. Connectivity Analysis in EEG Data: A Tutorial Review of the State of the Art and Emerging Trends. *Bioengineering* **2023**, *10*, 372.

Weiss, E.; Kann, M.; Wang, Q. Neuromodulation of Neural Oscillations in Health and Disease. *Biology* **2023**, *12*, 371.

Boucher, S.; Arribarat, G.; Cartiaux, B.; Lallemand, E.A.; Peran, P.; Deviers, A.; Mogicato, G. Diffusion Tensor Imaging Tractography of White Matter Tracts in the Equine Brain. *Front. Vet. Sci.* **2020**, *7*, 382.

Boukadi, M.; Marcotte, K.; Bedetti, C.; Houde, J.C.; Desautels, A.; Deslauriers-Gauthier, S.; Chapleau, M.; Bore, A.; Descoteaux, M.; Brambati, S.M. Test-Retest Reliability of Diffusion Measures Extracted Along White Matter Language Fiber Bundles Using HARDI-Based Tractography. *Front. Neurosci.* **2018**, *12*, 1055.

Shi, X.; Ma, X.; Wu, W.; Huang, F.; Yuan, C.; Guo, H. Parallel imaging and compressed sensing combined framework for accelerating high-resolution diffusion tensor imaging using inter-image correlation. *Magn. Reson. Med.* **2015**, *73*, 1775–1785.

Qiu, A.; Mori, S.; Miller, M.I. Diffusion tensor imaging for understanding brain development in early life. *Annu. Rev. Psychol.* **2015**, *66*, 853–876.

Radwan, A.M.; Sunaert, S.; Schilling, K.; Descoteaux, M.; Landman, B.A.; Vandenbulcke, M.; Theys, T.; Dupont, P.; Emsell, L. An atlas of white matter anatomy, its variability, and reproducibility based on constrained spherical deconvolution of diffusion MRI. *Neuroimage* **2022**, *254*, 119029.

Tae, W.S.; Ham, B.J.; Pyun, S.B.; Kang, S.H.; Kim, B.J. Current Clinical Applications of Diffusion-Tensor Imaging in Neurological Disorders. *J. Clin. Neurol.* **2018**, *14*, 129–140.

Andica, C.; Kamagata, K.; Hatano, T.; Saito, Y.; Ogaki, K.; Hattori, N.; Aoki, S. MR Biomarkers of Degenerative Brain Disorders Derived From Diffusion Imaging. *J. Magn. Reson. Imaging* **2020**, *52*, 1620–1636.

Kritikos, M.; Huang, C.; Clouston, S.A.P.; Pellecchia, A.C.; Santiago-Michels, S.; Carr, M.A.; Hagan, T.; Kotov, R.; Gandy, S.; Sano, M.; et al. DTI Connectometry Analysis Reveals White Matter Changes in Cognitively Impaired World Trade Center Responders at Midlife. *J. Alzheimers Dis.* **2022**, *89*, 1075–1089.

Lawlor-Savage, L.; Kusi, M.; Clark, C.M.; Goghari, V.M. No evidence for an effect of a working memory training program on white matter microstructure. *Intelligence* **2021**, *86*, 101541.

Guo, W.; He, Y.; Zhang, W.; Sun, Y.; Wang, J.; Liu, S.; Ming, D. A novel non-invasive brain stimulation technique: “Temporally interfering electrical stimulation”. *Front. Neurosci.* **2023**, *17*, 1092539.

Li, K.P.; Wu, J.J.; Zhou, Z.L.; Xu, D.S.; Zheng, M.X.; Hua, X.Y.; Xu, J.G. Noninvasive Brain Stimulation for Neurorehabilitation in Post-Stroke Patients. *Brain Sci.* **2023**, *13*, 451.

Krause, M.R.; Vieira, P.G.; Pack, C.C. Transcranial electrical stimulation: How can a simple conductor orchestrate complex brain activity? *PLoS Biol.* **2023**, *21*, e3001973.

Parlikar, R.; Vanteemar, S.S.; Shivakumar, V.; Narayanaswamy, C.J.; Rao, P.N.; Ganesan, V. High definition transcranial direct current stimulation (HD-tDCS): A systematic review on the treatment of neuropsychiatric disorders. *Asian J. Psychiatr.* **2021**, *56*, 102542.

Yavari, F.; Nitsche, M.A.; Ekhtiari, H. Transcranial Electric Stimulation for Precision Medicine: A Spatiomechanistic Framework. *Front. Hum. Neurosci.* **2017**, *11*, 159.

Bouchard, A.E.; Dickler, M.; Renauld, E.; Lenglos, C.; Ferland, F.; Rouillard, C.; Leblond, J.; Fecteau, S. Concurrent Transcranial Direct Current Stimulation and Resting-State Functional Magnetic Resonance Imaging in Patients with Gambling Disorder. *Brain Connect.* **2021**, *11*, 815–821.

Nardo, D.; Creasey, M.; Negus, C.; Pappa, K.; Aghaeifar, A.; Reid, A.; Josephs, O.; Callaghan, M.F.; Crinion, J.T. Transcranial direct current stimulation with functional magnetic resonance

Yang, D.; Shin, Y.I.; Hong, K.S. Systemic Review on Transcranial Electrical Stimulation Parameters and EEG/fNIRS Features for Brain Diseases. *Front. Neurosci.* **2021**, *15*, 629323.

Yang, F.; Fang, X.; Tang, W.; Hui, L.; Chen, Y.; Zhang, C.; Tian, X. Effects and potential mechanisms of transcranial direct current stimulation (tDCS) on auditory hallucinations: A meta-analysis. *Psychiatry Res.* **2019**, *273*, 343–349.

Pacheco-Barrios, K.; Cardenas-Rojas, A.; Thibaut, A.; Costa, B.; Ferreira, I.; Caumo, W.; Fregni, F. Methods and strategies of tDCS for the treatment of pain: Current status and future directions. *Expert Rev. Med. Devices* **2020**, *17*, 879–898.

Lin, A.P.; Chiu, C.C.; Chen, S.C.; Huang, Y.J.; Lai, C.H.; Kang, J.H. Using High-Definition Transcranial Alternating Current Stimulation to Treat Patients with Fibromyalgia: A Randomized Double-Blinded Controlled Study. *Life* **2022**, *12*, 1364.

Brown, G.L.; Brown, M.T. Transcranial electrical stimulation in neurological disease. *Neural Regen. Res.* **2022**, *17*, 2221–2222.

Khan, A.; Yuan, K.; Bao, S.C.; Ti, C.H.E.; Tariq, A.; Anjum, N.; Tong, R.K. Can Transcranial Electrical Stimulation Facilitate Post-stroke Cognitive Rehabilitation? A Systematic Review and Meta-Analysis. *Front. Rehabil. Sci.* **2022**, *3*, 795737.

Chen, J.; Wang, Z.; Chen, Q.; Fu, Y.; Zheng, K. Transcranial Direct Current Stimulation Enhances Cognitive Function in Patients with Mild Cognitive Impairment and Early/Mid Alzheimer's Disease: A Systematic Review and Meta-Analysis. *Brain Sci.* **2022**, *12*, 562.

Iordan, A.D.; Ryan, S.; Tyszkowski, T.; Peltier, S.J.; Rahman-Filipiak, A.; Hampstead, B.M. High-definition transcranial direct current stimulation enhances network segregation during spatial navigation in mild cognitive impairment. *Cereb. Cortex* **2022**, *32*, 5230–5241.

Brunelin, J.; Mondino, M.; Gassab, L.; Haesebaert, F.; Gaha, L.; Suaud-Chagny, M.F.; Saoud, M.; Mechri, A.; Poulet, E. Examining transcranial direct-current stimulation (tDCS) as a treatment for hallucinations in schizophrenia. *Am. J. Psychiatry* **2012**, *169*, 719–724.

Mondino, M.; Jardri, R.; Suaud-Chagny, M.F.; Saoud, M.; Poulet, E.; Brunelin, J. Effects of Fronto-Temporal Transcranial Direct Current Stimulation on Auditory Verbal Hallucinations and Resting-State Functional Connectivity of the Left Temporo-Parietal Junction in Patients With Schizophrenia. *Schizophr. Bull.* **2016**, *42*, 318–326.

Straudi, S.; Buja, S.; Baroni, A.; Pavarelli, C.; Pranovi, G.; Fregni, F.; Basaglia, N. The effects of transcranial direct current stimulation (tDCS) combined with group exercise treatment in subjects with chronic low back pain: A pilot randomized control trial. *Clin. Rehabil.* **2018**, *32*, 1348–1356.

Luedtke, K.; Rushton, A.; Wright, C.; Jurgens, T.; Polzer, A.; Mueller, G.; May, A. Effectiveness of transcranial direct current stimulation preceding cognitive behavioural management for chronic low back pain: Sham controlled double blinded randomised controlled trial. *BMJ* **2015**, *350*, h1640.

Arutiunian, V.; Gomozova, M.; Minnigulova, A.; Davydova, E.; Pereverzeva, D.; Sorokin, A.; Tyushkevich, S.; Mamokhina, U.; Danilina, K.; Dragoy, O. Structural brain abnormalities and their association with language impairment in school-aged children with Autism Spectrum Disorder. *Sci. Rep.* **2023**, *13*, 1172.

Bartolotti, J.; Sweeney, J.A.; Mosconi, M.W. Functional brain abnormalities associated with comorbid anxiety in autism spectrum disorder. *Dev. Psychopathol.* **2020**, *32*, 1273–1286.

Salari, N.; Rasoulpoor, S.; Rasoulpoor, S.; Shohaimi, S.; Jafarpour, S.; Abdoli, N.; Khaledi-Paveh, B.; Mohammadi, M. The global prevalence of autism spectrum disorder: A comprehensive systematic review and meta-analysis. *Ital. J. Pediatr.* **2022**, *48*, 112.

Shehata, L.A.O.; Ibrahim, O.; El-Kammash, T.H.; Gad, A.A. Brain volumetric and white matter structural connectivity alterations in autistic children: Case–control study. *Egypt. J. Radiol. Nucl. Med.* **2023**, *54*, 36.

Nisar, S.; Haris, M. Neuroimaging genetics approaches to identify new biomarkers for the early diagnosis of autism spectrum disorder. *Mol. Psychiatry* **2023**, 1–14.

Wolff, J.J.; Jacob, S.; Elison, J.T. The journey to autism: Insights from neuroimaging studies of infants and toddlers. *Dev. Psychopathol.* **2018**, *30*, 479–495.

Ha, S.; Sohn, I.J.; Kim, N.; Sim, H.J.; Cheon, K.A. Characteristics of Brains in Autism Spectrum Disorder: Structure, Function and Connectivity across the Lifespan. *Exp. Neurobiol.* **2015**, *24*, 273–284.

Duan, X.; Chen, H. Mapping brain functional and structural abnormities in autism spectrum disorder: Moving toward precision treatment. *Psychoradiology* **2022**, *2*, 78–85.

Desaunay, P.; Guillery, B.; Moussaoui, E.; Eustache, F.; Bowler, D.M.; Guenole, F. Brain correlates of declarative memory atypicalities in autism: A systematic review of functional neuroimaging findings. *Mol. Autism* **2023**, *14*, 2.

Goodwill, A.M.; Low, L.T.; Fox, P.T.; Fox, P.M.; Poon, K.K.; Bhowmick, S.S.; Chen, S.H.A. Meta-analytic connectivity modelling of functional magnetic resonance imaging studies in autism spectrum disorders. *Brain Imaging Behav.* **2023**, *17*, 257–269.

Gibbard, C.R.; Ren, J.; Skuse, D.H.; Clayden, J.D.; Clark, C.A. Structural connectivity of the amygdala in young adults with autism spectrum disorder. *Hum. Brain Mapp.* **2018**, *39*, 1270–1282.

Li, X.; Zhang, K.; He, X.; Zhou, J.; Jin, C.; Shen, L.; Gao, Y.; Tian, M.; Zhang, H. Structural, Functional, and Molecular Imaging of Autism Spectrum Disorder. *Neurosci. Bull.* **2021**, *37*, 1051–1071.

Ali, H.; Rahman, H.; Lee, L.C.; Khan, N.Z.; Wu, L.S.; Mehra, S.; Mitra, M.; Labrique, A.B.; West, K.P., Jr.; Christian, P. Autism spectrum disorder in a rural community in Bangladesh: A mid-childhood assessment. *Autism Res.* **2022**, *15*, 328–339.

Breda, V.; Rohde, L.A.; Menezes, A.M.B.; Anselmi, L.; Caye, A.; Rovaris, D.L.; Vitola, E.S.; Bau, C.H.D.; Grevet, E.H. The neurodevelopmental nature of attention-deficit hyperactivity disorder in adults. *Br. J. Psychiatry* **2021**, *218*, 43–50.

von Gontard, A.; Hussong, J.; Yang, S.S.; Chase, J.; Franco, I.; Wright, A. Neurodevelopmental disorders and incontinence in children and adolescents: Attention-deficit/hyperactivity disorder, autism spectrum disorder, and intellectual disability-A consensus document of the International Children's Continence Society. *Neurourol. Urodyn.* **2022**, *41*, 102–114.

Soman, S.M.; Vijayakumar, N.; Thomson, P.; Ball, G.; Hyde, C.; Silk, T.J. Functional and structural brain network development in children with attention deficit hyperactivity disorder. *Hum. Brain Mapp.* **2023**, *44*, 3394–3409.

Gonchigsuren, O.; Harada, M.; Hisaoka, S.; Higashi, K.; Matsumoto, Y.; Sumida, N.; Mori, T.; Ito, H.; Mori, K.; Miyoshi, M. Brain abnormalities in children with attention-deficit/hyperactivity disorder assessed by multi-delay arterial spin labeling perfusion and voxel-based morphometry. *Jpn. J. Radiol.* **2022**, *40*, 568–577.

Long, Y.; Pan, N.; Ji, S.; Qin, K.; Chen, Y.; Zhang, X.; He, M.; Suo, X.; Yu, Y.; Wang, S.; et al. Distinct brain structural abnormalities in attention-deficit/hyperactivity disorder and substance use disorders: A comparative meta-analysis. *Transl. Psychiatry* **2022**, *12*, 368.

Gehricke, J.G.; Kruggel, F.; Thampipop, T.; Alejo, S.D.; Tatos, E.; Fallon, J.; Muftuler, L.T. The brain anatomy of attention-deficit/hyperactivity disorder in young adults—A magnetic resonance imaging study. *PLoS ONE* **2017**, *12*, e0175433.

Tang, X.; Seymour, K.E.; Crocetti, D.; Miller, M.I.; Mostofsky, S.H.; Rosch, K.S. Response control correlates of anomalous basal ganglia morphology in boys, but not girls, with attention-deficit/hyperactivity disorder. *Behav. Brain Res.* **2019**, *367*, 117–127.

Rubia, K. Cognitive Neuroscience of Attention Deficit Hyperactivity Disorder (ADHD) and Its Clinical Translation. *Front. Hum. Neurosci.* **2018**, *12*, 100.

Tabiee, M.; Azhdarloo, A.; Azhdarloo, M. Comparing executive functions in children with attention deficit hyperactivity disorder with or without reading disability: A resting-state EEG study. *Brain Behav.* **2023**, *13*, e2951.

D'Urso, G.; Toscano, E.; Sanges, V.; Sauvaget, A.; Sheffer, C.E.; Riccio, M.P.; Ferrucci, R.; Iasevoli, F.; Priori, A.; Bravaccio, C.; et al. Cerebellar Transcranial Direct Current Stimulation in Children with Autism Spectrum Disorder: A Pilot Study on Efficacy, Feasibility, Safety, and Unexpected Outcomes in Tic Disorder and Epilepsy. *J. Clin. Med.* **2021**, *11*, 143.

Garcia-Gonzalez, S.; Lugo-Marin, J.; Setien-Ramos, I.; Gisbert-Gustemps, L.; Arteaga-Henriquez, G.; Diez-Villoria, E.; Ramos-Quiroga, J.A. Transcranial direct current stimulation in Autism Spectrum Disorder: A systematic review and meta-analysis. *Eur. Neuropsychopharmacol.* **2021**, *48*, 89–109.

Luckhardt, C.; Schutz, M.; Muhlherr, A.; Mossinger, H.; Boxhoorn, S.; Dempfle, A.; Salvador, R.; Ruffini, G.; Pereira, H.C.; Castelo-Branco, M.; et al. Phase-IIa randomized, double-blind, sham-controlled, parallel group trial on anodal transcranial direct current stimulation (tDCS) over the left and right tempo-parietal junction in autism spectrum disorder-StimAT: Study protocol for a clinical trial. *Trials* **2021**, *22*, 248.

Prillinger, K.; Radev, S.T.; Amador de Lara, G.; Klobl, M.; Lanzenberger, R.; Plener, P.L.; Poustka, L.; Konicar, L. Repeated Sessions of Transcranial Direct Current Stimulation on Adolescents With Autism Spectrum Disorder: Study Protocol for a Randomized, Double-Blind, and Sham-Controlled Clinical Trial. *Front. Psychiatry* **2021**, *12*, 680525.

Qiu, J.; Kong, X.; Li, J.; Yang, J.; Huang, Y.; Huang, M.; Sun, B.; Su, J.; Chen, H.; Wan, G.; et al. Transcranial Direct Current Stimulation (tDCS) over the Left Dorsal Lateral Prefrontal Cortex in Children with Autism Spectrum Disorder (ASD). *Neural Plast.* **2021**, *2021*, 6627507.

Auvichayapat, P.; Intayot, K.; Udomchat, C.; Suphakunpinyo, C.; Patjanasoontorn, N.; Keeratitanont, K.; Tunkamnerdthai, O.; Jensen, M.P.; Humbert, A.T.; Auvichayapat, N. Long-term effects of transcranial direct current stimulation in the treatment of autism spectrum disorder: A randomized controlled trial. *Dev. Med. Child Neurol.* **2022**, *65*, 811–820.

Sousa, B.; Martins, J.; Castelo-Branco, M.; Goncalves, J. Transcranial Direct Current Stimulation as an Approach to Mitigate Neurodevelopmental Disorders Affecting Excitation/Inhibition Balance: Focus on Autism Spectrum Disorder, Schizophrenia, and Attention Deficit/Hyperactivity Disorder. *J. Clin. Med.* **2022**, *11*, 2839.

Sun, C.; Zhao, Z.; Cheng, L.; Tian, R.; Zhao, W.; Du, J.; Zhang, Y.; Wang, C. Effect of Transcranial Direct Current Stimulation on the Mismatch Negativity Features of Deviated Stimuli in Children With Autism Spectrum Disorder. *Front. Neurosci.* **2022**, *16*, 721987. [

Wilson, J.E. Transcranial direct current stimulation for children with autism spectrum disorder: Implications for school-based settings. *Dev. Med. Child Neurol.* **2022**, *65*, 730–731.

Kang, J.; Fan, X.; Zhong, Y.; Casanova, M.F.; Sokhadze, E.M.; Li, X.; Niu, Z.; Geng, X. Transcranial Direct Current Stimulation Modulates EEG Microstates in Low-Functioning Autism: A Pilot Study. *Bioengineering* **2023**, *10*, 98.

Barham, H.; Buyukgok, D.; Aksu, S.; Soyata, A.Z.; Bulut, G.; Eskicioglu, G.; Baral Kulaksizoglu, I. Evidence for modulation of planning and working memory capacities by transcranial direct current stimulation in a sample of adults with attention deficit hyperactivity disorder. *Neurosci. Lett.* **2022**, *790*, 136883.

Dubreuil-Vall, L.; Gomez-Bernal, F.; Villegas, A.C.; Cirillo, P.; Surman, C.; Ruffini, G.; Widge, A.S.; Camprodon, J.A. Transcranial Direct Current Stimulation to the Left Dorsolateral Prefrontal Cortex Improves Cognitive Control in Patients with Attention-Deficit/Hyperactivity Disorder: A Randomized Behavioral and Neurophysiological Study. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* **2021**, *6*, 439–

Guimaraes, R.S.Q.; Bandeira, I.D.; Barretto, B.L.; Barretto, T.L.; Wanke, T.; Alves, C.O.C.; de Carvalho, C.F.; Lucena, P.H.; Rodrigues-Silva, L.; Lucena, R. The effects of transcranial direct current stimulation on attention and inhibitory control of children and adolescents with attention-deficit/hyperactivity disorder (ADHD): Study protocol for a randomized, sham-controlled, triple-blind, cross-over trial. *Medicine* **2021**, *100*, e24283.

Leffa, D.T.; Grevet, E.H.; Bau, C.H.D.; Schneider, M.; Ferrazza, C.P.; da Silva, R.F.; Miranda, M.S.; Picon, F.; Teche, S.P.; Sanches, P.; et al. Transcranial Direct Current Stimulation vs Sham for the Treatment of Inattention in Adults with Attention-Deficit/Hyperactivity Disorder: The TUNED Randomized Clinical Trial. *JAMA Psychiatry* **2022**, *79*, 847–856.

Nejati, V.; Movahed Alavi, M.; Nitsche, M.A. The Impact of Attention Deficit-hyperactivity Disorder Symptom Severity on the Effectiveness of Transcranial Direct Current Stimulation (tDCS) on Inhibitory Control. *Neuroscience* **2021**, *466*, 248–257.

Wang, Y.C.; Liu, J.; Wu, Y.C.; Wei, Y.; Xie, H.J.; Zhang, T.; Zhang, Z. A randomized, sham-controlled trial of high-definition transcranial direct current stimulation on the right orbital frontal cortex in children and adolescents with attention-deficit hyperactivity disorder. *Front. Psychiatry* **2023**, *14*, 987093.

Wang, H.; Wang, L.S.; Schellenberg, G.; Lee, W.P. The role of structural variations in Alzheimer's disease and other neurodegenerative diseases. *Front. Aging Neurosci.* **2022**, *14*, 1073905.

Chiang, M.C.; Tsai, T.Y.; Wang, C.J. The Potential Benefits of Quercetin for Brain Health: A Review of Anti-Inflammatory and Neuroprotective Mechanisms. *Int. J. Mol. Sci.* **2023**, *24*, 6328.

Chiang, M.C.; Cheng, Y.C.; Chen, S.J.; Yen, C.H.; Huang, R.N. Metformin activation of AMPK-dependent pathways is neuroprotective in human neural stem cells against Amyloid-beta-induced mitochondrial dysfunction. *Exp. Cell Res.* **2016**, *347*, 322–331.

Chiang, M.C.; Nicol, C.J.; Cheng, Y.C. Resveratrol activation of AMPK-dependent pathways is neuroprotective in human neural stem cells against amyloid-beta-induced inflammation and oxidative stress. *Neurochem. Int.* **2018**, *115*, 1–10.

Rajah Kumaran, K.; Yunusa, S.; Perimal, E.; Wahab, H.; Muller, C.P.; Hassan, Z. Insights into the Pathophysiology of Alzheimer's Disease and Potential Therapeutic Targets: A Current Perspective. *J. Alzheimers Dis.* **2023**, *91*, 507–530.

Giannakopoulos, P.; Rodriguez, C.; Montandon, M.L.; Garibotto, V.; Haller, S.; Herrmann, F.R. Personality Impact on Alzheimer's Disease—Signature and Vascular Imaging Markers: A PET-MRI Study. *J. Alzheimers Dis.* **2022**, *85*, 1807–1817.

Schwarz, A.J. The Use, Standardization, and Interpretation of Brain Imaging Data in Clinical Trials of Neurodegenerative Disorders. *Neurotherapeutics* **2021**, *18*, 686–708.

Rittman, T. Neurological update: Neuroimaging in dementia. *J. Neurol.* **2020**, *267*, 3429–3435.

Rao, Y.L.; Ganaraja, B.; Murlimanju, B.V.; Joy, T.; Krishnamurthy, A.; Agrawal, A. Hippocampus and its involvement in Alzheimer's disease: A review. *3 Biotech* **2022**, *12*, 55.

Marquez, F.; Yassa, M.A. Neuroimaging Biomarkers for Alzheimer's Disease. *Mol. Neurodegener.* **2019**, *14*, 21.

Ardanaz, C.G.; Ramirez, M.J.; Solas, M. Brain Metabolic Alterations in Alzheimer's Disease. *Int. J. Mol. Sci.* **2022**, *23*, 3785.

Zhang, M.; Guan, Z.; Zhang, Y.; Sun, W.; Li, W.; Hu, J.; Li, B.; Ye, G.; Meng, H.; Huang, X.; et al. Disrupted coupling between salience network segregation and glucose metabolism is associated with cognitive decline in Alzheimer's disease—A simultaneous resting-state FDG-PET/fMRI study. *Neuroimage Clin.* **2022**, *34*, 102977.

Su, D.; Gan, Y.; Zhang, Z.; Cui, Y.; Zhang, Z.; Liu, Z.; Wang, Z.; Zhou, J.; Sossi, V.; Stoessl, A.J.; et al. Multimodal Imaging of Substantia Nigra in Parkinson's Disease with Levodopa-Induced Dyskinesia. *Mov. Disord.* **2023**, *38*, 616–625.

Readman, M.R.; Crawford, T.J.; Linkenauger, S.A.; Bek, J.; Poliakoff, E. Motor imagery vividness and symptom severity in Parkinson's disease. *J. Neuropsychol.* **2023**, *17*, 180–192.

Hou, Y.; Zhang, L.; Ou, R.; Wei, Q.; Gu, X.; Liu, K.; Lin, J.; Yang, T.; Xiao, Y.; Gong, Q.; et al. Motor progression marker for newly diagnosed drug-naive patients with Parkinson's disease: A resting-state functional MRI study. *Hum. Brain Mapp.* **2023**, *44*, 901–913.

Bidesi, N.S.R.; Vang Andersen, I.; Windhorst, A.D.; Shalgunov, V.; Herth, M.M. The role of neuroimaging in Parkinson's disease. *J. Neurochem.* **2021**, *159*, 660–689.

Aarsland, D.; Batzu, L.; Halliday, G.M.; Geurtsen, G.J.; Ballard, C.; Ray Chaudhuri, K.; Weintraub, D. Parkinson disease-associated cognitive impairment. *Nat. Rev. Dis. Prim.* **2021**, *7*, 47.

McGregor, M.M.; McKinsey, G.L.; Girasole, A.E.; Bair-Marshall, C.J.; Rubenstein, J.L.R.; Nelson, A.B. Functionally Distinct Connectivity of Developmentally Targeted Striosome Neurons. *Cell Rep.* **2019**, *29*, 1419–1428.e5.

McGregor, M.M.; Nelson, A.B. Circuit Mechanisms of Parkinson's Disease. *Neuron* **2019**, *101*, 1042–1056.

Rajji, T.K. Transcranial Magnetic and Electrical Stimulation in Alzheimer's Disease and Mild Cognitive Impairment: A Review of Randomized Controlled Trials. *Clin. Pharm.* **2019**, *106*, 776–780.

Pini, L.; Pizzini, F.B.; Boscolo-Galazzo, I.; Ferrari, C.; Galluzzi, S.; Cotelli, M.; Gobbi, E.; Cattaneo, A.; Cotelli, M.S.; Geroldi, C.; et al. Brain network modulation in Alzheimer's and frontotemporal dementia with transcranial electrical stimulation. *Neurobiol. Aging* **2022**, *111*, 24–34.

Andrade, S.M.; Machado, D.; Silva-Sauerc, L.D.; Regis, C.T.; Mendes, C.; de Araujo, J.S.S.; de Araujo, K.D.T.; Costa, L.P.; Queiroz, M.; Leitao, M.M.; et al. Effects of multisite anodal transcranial direct current stimulation combined with cognitive stimulation in patients with Alzheimer's disease and its neurophysiological correlates: A double-blind randomized clinical trial. *Neurophysiol. Clin.* **2022**, *52*, 117–127.

Marchi, L.Z.; Ferreira, R.G.D.; de Lima, G.N.S.; da Silva, J.A.S.; da Cruz, D.M.C.; Fernandez-Calvo, B.; Andrade, S. Multisite transcranial direct current stimulation associated with cognitive training in episodic memory and executive functions in individuals with Alzheimer's disease: A case report. *J. Med. Case Rep.* **2021**, *15*, 185.

Rasmussen, I.D.; Boayue, N.M.; Mittner, M.; Bystad, M.; Gronli, O.K.; Vangberg, T.R.; Csifcsak, G.; Aslaksen, P.M. High-Definition Transcranial Direct Current Stimulation Improves Delayed Memory in Alzheimer's Disease Patients: A Pilot Study Using Computational Modeling to Optimize Electrode Position. *J. Alzheimers Dis.* **2021**, *83*, 753–769.

Saxena, V.; Pal, A. Role of Transcranial Direct Current Stimulation in the Management of Alzheimer's Disease: A Meta-analysis of Effects, Adherence and Adverse Effects. *Clin. Psychopharmacol. Neurosci.* **2021**, *19*, 589–599.

التطورات في التصوير بالرنين المغناطيسي الوظيفي: التطبيقات في الاضطرابات العصبية والنفسية

الملخص:

خلفية: أصبح التصوير العصبي الوظيفي حجر الزاوية في دراسة نشاط الدماغ، مما يتيح استكشاف الهيكل والوظيفة الدماغية بشكل غير تدخلي. لقد قدمت تقنيات مثل التصوير بالرنين المغناطيسي الوظيفي(fMRI) ، تخطيط الدماغ الكهربائي(EEG) ، التصوير المقطعي بالإصدار البوزيتروني(PET) ، وتخطيط دماغ المغناطيسي (MEG) رؤى لا تقدر بثمن حول الآليات العصبية التي تكمن وراء العمليات الإدراكية والعاطفية والسلوكية. يتيح التصوير بالرنين المغناطيسي الوظيفي، على وجه الخصوص، رسم خرائط دقيقة للمناطق الدماغية من خلال مستويات الأوكسجين في الدم، بينما يلتقط EEG النشاط الكهربائي للدماغ بدقة زمنية عالية. لقد غيرت هذه الأساليب من فهم الاضطرابات العصبية والنفسية، مقدمة إمكانيات تشخيصية وعلاجية.

الهدف: يستكشف هذا المقال أحدث التطورات في تقنيات التصوير بالرنين المغناطيسي الوظيفي وEEG، مع التركيز على تطبيقاتها في الاضطرابات العصبية والنفسية. يهدف إلى تقديم نظرة شاملة حول كيفية تطبيق هذه

التقنيات لفك تشفير الأسس العصبية للاضطرابات مثل مرض الزهايمر، ومرض باركنسون، والفصام، والاكتئاب.

الطرق: تم إجراء مراجعة منهجية لأحدث الأدبيات المتعلقة بتطورات fMRI وEEG، مع تسليط الضوء على المنهجيات الجديدة، والتحسينات في الدقة المكانية والزمنية، واستخدامها المشترك في التصوير متعدد الأوضاع. تم تحليل الدراسات الرئيسية التي توضح تطبيق هذه التقنيات في الإعدادات السريرية والبحثية.

النتائج: توسعت الفهم الخاص بالاتصال الدماغي والخلل الوظيفي بفضل التطورات التكنولوجية الحديثة في التصوير بالرنين المغناطيسي الوظيفي، مثل الدقة المكانية الأعلى، والتصوير في الوقت الحقيقي، والدمج متعدد الأوضاع. كما أن التطورات فيEEG ، بما في ذلك شبكات الأقطاب الكهربائية عالية الكثافة وتحديد المصدر في الوقت الحقيقي، قد عززت دقة تتبع التذبذبات العصبية والاتصال الدماغي. معًا، ساهمت هذه الابتكارات في تحسين تشخيص وعلاج العديد من الحالات العصبية والنفسية.

الخاتمة: لقد أثرت التطورات في تقنيات التصوير بالرنين المغناطيسي الوظيفي و EEGبشكل كبير في دراسة وظائف الدماغ، خاصة في فهم المرضيات العصبية والنفسية. لم تقتصر هذه التقنيات على تعزيز الدقة المكانية والزمنية في تصوير الدماغ فحسب، بل مهدت أيضًا الطريق للعلاج الشخصي في معالجة هذه الحالات.

الكلمات المفتاحية: التصوير بالرنين المغناطيسي الوظيفي(fMRI) ، EEG، التصوير العصبي، وظيفة الدماغ، الاضطرابات العصبية، الاضطرابات النفسية، الاتصال الدماغي، التصوير متعدد الأوضاع، الدقة المكانية، الدقة الزمنية.