Techniques, Advantages and Limitations of Neuroimaging: A Systematic Review

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Abstract – Neuroimaging was developed as a non-invasive and objective technique for studying the function and structure of the normal human brain, utilizing quantitative computational methods. The utilization of quantitative research in the study of neurological and mental health disorders is experiencing a notable increase. While there are post-residency programs offered in the field of Neuro-Radiology, it is important to note that neuroimaging is not recognized as an independent medical specialty. An increasing number of studies are placing emphasis on matters pertaining to rehabilitation. Hence, possessing a fundamental understanding of the prevailing neuroimaging approaches is crucial for comprehending and analyzing this rapidly evolving research area. This article provides an overview of the signal source, reviews the advantages and limitations associated with the techniques, and presents a comprehensive evaluation of the field. Functional magnetic resonance imaging (fMRI) has materialized as a prominent tool within the realm of rehabilitation science due to its widespread utilization and significance.

Keywords – Neuroimaging, Functional Magnetic Resonance Imaging, Magnetoencephalography, Positron Emission Tomography, Electroencephalograph, Functional Near-Infrared Spectroscopy.

I. INTRODUCTION

The role of human behavior and, at a more fundamental level, the human brain, has been widely recognized as crucial in the advancement of innovative technology. The field of laboratory-based experimental neurotechnologies has witnessed notable progress in the last thirty years, resulting in valuable and intricate understandings of the relationship between human experience and the function and structure of the nervous system. The aforementioned connection is widely regarded as the fundamental basis for comprehending the mechanisms by which we detect, interpret, and engage with the surrounding environment. The existing body of theoretical and experimental evidence indicates that the functioning of the human brain in regulating behavior within ecologically-valid contexts, known as situated cognition, may exhibit fundamental differences compared to observations made in tightly-controlled laboratory settings. The issue of generalizability underscores the importance of transferring neuroimaging technology from controlled laboratory environments to more realistic settings, enabling the exploration of human interactions, tasks, and environments. The expansion of neurotechnologies is expected to have a significant impact on the advancement of innovative brain-computer interface technologies (BCITs) [1]. BCITs possess the potential to revolutionize human-systems communication by facilitating the analysis, interpretation, and prediction of data generated by both humans and machines. The latter skill is an essential competency that has the potential to greatly enhance interactions between humans and systems across various domains of life.

Various neuroimaging techniques such as magnetoencephalography (MEG) [2], positron emission tomography (PET) [3], functional near-infrared spectroscopy (fNIRS) [4], functional magnetic resonance imaging (fMRI) [5], and electroencephalography (EEG) [6], have provided significant contributions to our comprehension of the brain function, structure, and the underlying mechanisms involved in the development of mental representations and behavior. A significant portion of our current understanding of the brain has been derived from research conducted under artificial laboratory conditions, which may not faithfully represent real-world circumstances. This approach has facilitated the acquisition of knowledge regarding the fundamental mechanisms of the brain. However, the extent to which the insights gained from controlled laboratory settings can be applied to comprehending the intricate and dynamic conditions of the real world remains uncertain.

There are scholars who argue that it is more advantageous to avoid generalizing findings to real-life scenarios, as doing so may lead to fundamental misunderstandings about the functioning of the brain in natural contexts. These concerns arise from the limited application of neuroimaging techniques in more realistic environments. The existence of approximately one quadrillion neural connections in the human brain has been postulated and empirically validated. These connections facilitate distinct information processing among individuals and can even necessitate such differences. Moreover, it has been observed that individuals may activate different brain regions to cognitively process similar information, particularly when confronted with contextual variations. These concepts suggest the potential existence of significant differences between cognition that occurs in real-world contexts and cognition that occurs in controlled laboratory environments. This supports the argument for placing more importance on ecological research methods that consider the dynamic relationship between individuals, tasks, and their surrounding contexts. The primary motivation driving our endeavors to perform neuroimaging in real-world environments is the potential to facilitate the translation of fundamental neuroscience findings into technological advancements.

In recent times [7] have made efforts to expand the boundaries of neuroimaging by incorporating more complex scenarios that were previously considered unsolvable, despite employing state-of-the-art methodologies. The majority of these initiatives have utilized neuroimaging technologies originally designed for laboratory purposes in order to fulfill specific and unconventional measurement requirements. Significant progress has been achieved by researchers in this field; however, it remains relatively underdeveloped due to the inherent challenge of reconciling the investigation of tightly regulated, potentially contrived behaviors with the need to ensure the applicability of findings to ecological contexts in the real world. Current neuroimaging technologies are inadequate for conducting a comprehensive investigation in real-world environments, thereby constraining the scope and thoroughness of the study. Given the intricate dynamics and inherent uncertainties present in real-world scenarios, along with the multitude of factors that limit the signal-to-noise ratio, the development of such tools necessitates more than a simple expansion of current laboratory-based technology.

In recent times, there have been notable advancements in new technologies, which hold great promise in enhancing clinical neuroimaging. The aforementioned advancements facilitate the creation of preliminary system designs; however, the practical application of neuroimaging in real-world scenarios necessitates progress in four fundamental technological domains. Neuroimaging hardware that is designed to be wearable and applicable in real-world scenarios encompasses various components, including multi-aspect sensor arrays, batteries, and on-board processing capabilities. The integration of various sensors and the utilization of algorithms have facilitated the joint analysis of brain signals, human behavior, and environmental context. These algorithms are capable of addressing diverse challenges, including low signal-to-noise ratios and the integration of multiple sensor types.

This article explores novel approaches in neuroimaging under conditions of uncertainty, as well as technologies that can be used to validate new hardware and algorithms. Additionally, it investigates the advantages and limitations. The remainder of the article has been organized as follows: Section II presents a background analysis of the human brain mapping, as well as the rationale of the paper. Section III presents a critical evaluation of neuroimaging techniques such as MEG, PET, TMS, and MRI. In Section IV, a discussion of the advantages and limitations of neuroimaging techniques is provided. Finally, Section V presents concluding remarks regarding the research.

II. HISTORICAL BACKGROUND

For more than two centuries, researchers have been engaged in the endeavor of mapping brain activity. During the early 19th century, phrenologists introduced the initial widely adopted methodology. In [8], it is postulated that the influence of a cognitive function on behavior exhibited a direct correlation with the amount of brain tissue allocated to it. The researchers hypothesized that the enlargement of brain size would manifest as detectable protrusions on the skull, even though they were unable to directly measure cortical volume. Although phrenology may have been deficient in terms of scientific consistency, it did present the ideology of the localization of the brain function, which postulates that particular human behavior aspects are predominantly associated with distinct regions of the brain. Further advancements were made through the analysis of the repercussions of brain injury on individuals, such as the identification of language localization in stroke patients by Dwidar et al. [9]. Additionally, progress was made by investigating the impacts of stimulation on specific brain regions during neurosurgical procedures, as exemplified by Bogdanović et al.'s [10] identification of the motor cortex. The advent of novel neuroimaging technologies in the late 20th century revolutionized the field of functional localization research.

The study of the human brain has been made possible in both individuals with normal brain function and those with pathological conditions or injuries, owing to the advancements in noninvasive and minimally invasive methodologies. Multiple measurements can be obtained from a single individual using these methodologies. The methods that are most commonly employed include positron emission tomography (PET), functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), and magnetoencephalography (MEG). The realm of neuroimaging has traditionally been primarily influenced by the disciplines of neuroscience and psychology. Nevertheless, there is an increasing cohort of scholars who are utilizing these techniques to investigate issues associated with rehabilitation. The development of effective remedies necessitates a comprehensive understanding of the scientific underpinnings of illnesses, problems, and healing. Neuro-imaging techniques are employed by rehabilitation experts to gain a deeper comprehension of the mechanisms by which treatments enhance functional capabilities.

Hence, the objective of this paper is to offer a concise review of the neuroimaging methodologies typically employed, specifically emphasizing fMRI, which is the predominant approach utilized in the realm of rehabilitation. This composition was not originally intended for individuals specializing in the field of physics or those with expertise in anti-aging research. The present article elucidates the underlying principles and mechanisms of functional magnetic resonance imaging (fMRI), delineates the crucial considerations that must be accounted for during the design and execution of an fMRI experiment, and expounds upon the methodologies employed by clinical technicians to assess the outcomes of fMRI-based investigations.

III. NEUROIMAGING TECHNIQUES

The aforementioned investigative methods possess distinct advantages and drawbacks that are contingent upon their respective strengths and limitations. The evaluation of various approaches is based on their level of privacy intrusion, task capabilities, data generation, and examination speed. When brain activity is precisely localized within the brain and when the measured brain activity aligns closely with the actual neural activity in terms of timing, it is referred to as having high temporal resolution and high spatial resolution. In contrast to invasive technologies that specifically monitor the activity of individual neurons, the methods under discussion in this context are limited in their ability to offer a comparable level of precision in interpreting brain activity. These techniques are expected to remain widely utilized for an extended period due to their preference over more intrusive methods of studying human brain activity.

Magnetoencephalography

Magnetoencephalography (MEG) refers to a non-invasive neuroimaging approach, which measures and detects the magnetic field produced by biological organisms. Typical brain functioning involves the presence of electrical currents, which are concomitant with associated fields. The magnetic fields that can be observed exhibit fluctuations that are synchronized with alterations in the flow of ionic currents, which are known to transpire during the functioning of the brain. Theoretical propositions suggest that the ability of magnetoencephalography (MEG) to detect neural signals is attributable to the activation of dendrites in the pyramidal tissues and cells in the cerebral cortex. Consequently, this method allows for a more direct measurement of cellular activities. MEG involves the strategic placement of sensors on the scalp in order to monitor the magnetic fields generated within the brain. In general, the sensors are affixed in a helmet-style configuration and positioned on the subject's head while they assume a seated or supine position on a table.

The readings obtained from each sensor provide insights into the synchronized neural activity of numerous neurons within the brain regions located beneath the sensor, specifically within the sulci. The observed pattern can be attributed to the inherent properties of the magnetic field. According to the established principle known as the "right-hand rule," the magnetic field exhibits a spiraling pattern around an electric current that is directed from the thumb to the index finger. If the current is concentrated vertical to the head's surface, the magnetic field tends to align in a parallel manner to the surface of the head, and will not permeate the detecting coils. The optimal direction for the magnetic field to be directed out of and into the head is achieved when the current flows perpendicularly to the surface. The induced field observed in the range of 501015T to 5001015T is smaller compared to the magnetic field of the Earth. In order to obtain a measurable reading from the current, it is necessary for both the study subject and the MEG tool to be located within a magnetically shielded chamber.

The MEG method exhibits sufficient flexibility to be applicable to a wide array of behavioral tests encompassing various sensory modalities such as vision, hearing, touch, and movement. Task-free baseline research can also be utilized to assess resting brain activity. To ascertain the regions of brain activation during a specific task, it is imperative to conduct an analysis of the collected data. The MEG analysis methodology incorporates various factors, including the consideration of the "inverse problem." While it is possible to determine the fields exterior to the head according to the currents in the interior of the head, the inverse problem does not have a single, definitive solution. The inclusion of additional information, such as simplicity assumption or dataset from other neuroimaging or neurophysiology investigations, has the potential to refine the findings and identify the most likely pattern of the brain activity. The MEG technique enables the assessment of the temporal neural activity sequence in the brain with remarkable temporal accuracy, typically within the range of 1 millisecond.

Additionally, it possesses the capability to offer a spatial resolution of 5 mm, rendering it an exceedingly valuable instrument. There are various methods available to present processed magnetoencephalography (MEG) data, such as magnetic field contour maps of the scalp or regions of brain activity superimposed on magnetic resonance imaging (MRI) of the skull. **Fig 1** presents the correlation existing between the surface of the scalp and the magnetic field. These are just a couple of examples among many. The aforementioned approach proves to be advantageous in examining the temporal patterns of brain activation, thereby offering insights into various aspects related to motor, cognitive, and sensory functions. Research by Zanella, Laures-Gore, Dotson, and Belagaje [11] on stroke and aphasia has demonstrated the efficacy of this approach in the context of rehabilitation.

Positron emission tomography

The utilization of molecules that have been tagged with radioisotopes is employed in the technique of positron emission tomography (PET). The term "label" refers to an isotope that undergoes positron emission. The isotopes of fluorine, oxygen, nitrogen, and carbon are frequently utilized in PET studies. The isotopes in question exhibit a brief half-life, typically vacillating from 2 minutes to approximately 2 hours. Due to this limited duration, it is necessary for a cyclotron, responsible for the production of these isotopes, to be located either on-site or in close proximity. Positron Emission Tomography (PET) involves the introduction of an isotope into a biologically significant chemical compound, which is subsequently administered to the individual via injection or inhalation. The subsequent concentration of the molecule is determined by its chemical properties as well as the metabolic and blood flow requirements of the brain. Upon the release of a positron from the molecule, it has the potential to be detected within these specific regions. When a positron and an electron collide within a distance of 1-2 mm, it results in the production of two gamma rays that exhibit an approximate phase difference of 180 degrees. When two gamma rays, which are moving in opposite directions, simultaneously interact with two photo-detectors, the positron emission tomography (PET) scanner detects this occurrence. The PET image is derived from these types of detections.

Positron emission tomography (PET) has the potential to provide quantitative assessments of various physiological parameters, including blood volume, blood flow, brain metabolism (specifically glucose metabolism), and neurotransmitter chemistry or neuroreceptor. This wide range of measurements is made possible by the diverse array of chemical tracers that can be employed in PET imaging. Positron Emission Tomography (PET) exhibits a spatial resolution of approximately 4-5 mm. The temporal resolution in functional investigations typically ranges from 1 to 2 minutes, as it is partial by both technological constraints and the metabolic characteristics of the molecules under study. PET investigations offer several advantages due to the utilization of various labeled molecules. For instance, the incorporation of labeled molecules such as C-labeled raclopride facilitates research on dopamine D2 receptors. Similarly, the use of 15O-labeled water enables the study of blood flow, while the employment of 2-fluoro-2-deoxy-D-glucose allows for investigations into brain metabolism. One limitation of this approach is the impracticality of conducting multiple scans due to the potential health risks associated with radiation exposure. This limitation impedes the ability to multitask effectively. Like MEG, the data can be presented in various formats, such as maps illustrating the spatial distribution of the categorized molecule or the modulation of brain activity in response to different tasks. One possible application involves the overlay of brain MRI scans with the aforementioned maps.

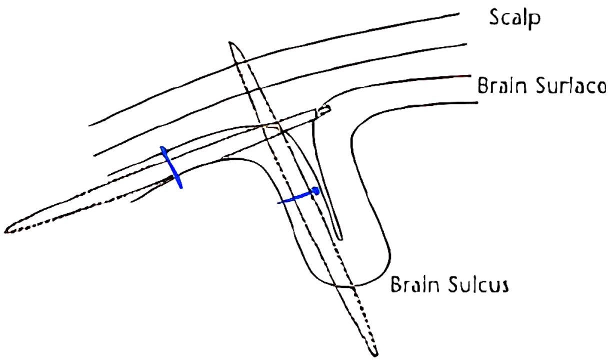

Fig 1. The correlation existing between the surface of the scalp and the magnetic field.

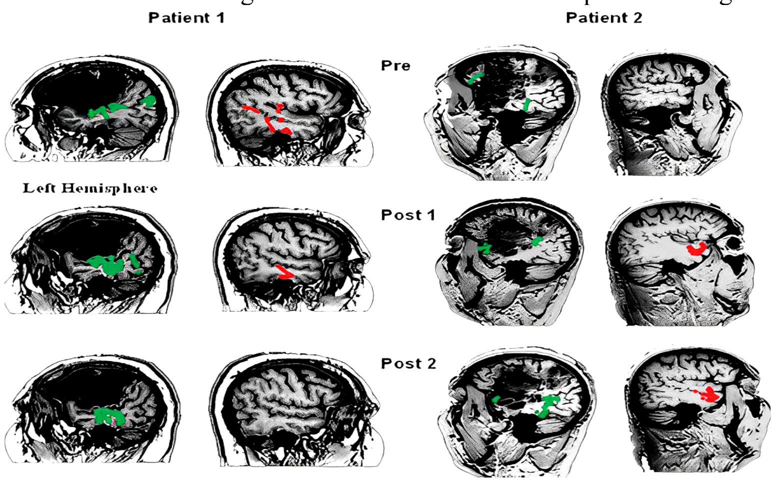

Fig 2. MEG-MRI scans on two patients

The arrows depicted in the diagram symbolize the trajectories of distinct electric currents, specifically one originating from the cerebral cortex and another emanating from a sulcus within the human brain. The magnetic field is represented by a dotted line. The measurement of the electromagnetic field produced by the brain's electrical activity is most effectively conducted by positioning a metal detector on the scalp. In the majority of instances, dipole activity within the primary visual cortex was observed at an early stage, preceding the resolution of the N1m.Due to its inherent nature of fundamental sensory processing, it was omitted from the analysis. **Fig 2** illustrates activation maps that are specific to language for each individual patient. Following the N1m resolution, it was witnessed that the middle, superior and lower temporal gyri, temporal pole, inferior frontal gyrus, and angular gyrus exhibited activity.

Patient 1, who is depicted on the left side of the image, exhibited a response to the treatment. Patient 2, on the figure's right side, did not respond to the treatment. **Fig 2** displays the individual dipoles that underwent thresholding after the resolution of the N1m. These dipoles are represented by red dots in the right hemisphere and green dots in the left hemisphere. The expected spatial separation of sources in the coronal plane is estimated to be a maximum of 1.5 centimeters.

Transcranial magnetic stimulation

Transcranial magnetic stimulation (TMS) is a contemporary and minimally invasive form of brain stimulation used in medical therapy to address psychiatric conditions. It involves the application of a pulsating magnetic coil to electrically excite the brain (see **Fig 3**, "Transcranial Magnetic Stimulation [TMS]"). Transcranial magnetic stimulation (TMS) has been observed to potentially enhance mood by triggering regions of the brain that are less active in individuals experiencing depression. The efficacy of electroconvulsive therapy (ECT) has been subject to scrutiny, yet transcranial magnetic stimulation (TMS) has demonstrated comparable effectiveness while obviating the requirement for sedation. Transcranial Magnetic Stimulation (TMS) therapy has demonstrated positive outcomes in the Parkinson's disease and schizophrenia treatment as well. Ongoing research is being conducted by Lewis, Annandale, Sykes, Hurlin, Owen, and K. Harrison [12] to explore supplementary biological interventions for individuals suffering from chronic and severe depression. The vagus nerve, a prominent neural pathway extending from the brainstem to the heart, can be activated through the utilization of an implanted device located within the thoracic cavity. The utilization of a device designed to stimulate the vagus nerve has demonstrated the ability to activate brain regions that exhibit inactivity in individuals experiencing severe depression.

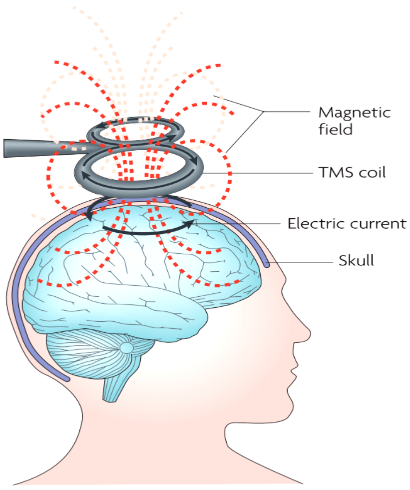

Fig 3. TMS employing a pulsating magnetic coil to prompt electrical stimulation of the brain

In recent times, transcranial magnetic stimulation (TMS) has been employed as a therapeutic intervention for individuals diagnosed with Parkinson's disease. In contrast to neuroimaging methodologies that primarily capture intrinsic brain activity, TMS involves the artificial stimulation of neurons through the employment of a magnetic field that stimulate electric current in the brain tissue. The utilization of brain activity manipulation has the potential to generate a comprehensive representation of brain function, shed light on the critical regions of the brain involved in specific task performance, and potentially serve as a therapeutic intervention. TMS entails the placement of a wire coil, arranged in either a circular or figure eight pattern, over the specific area of interest on the subject's cranium. When an electrical current is applied to the wire, it generates a magnetic field that can penetrate the scalp and skull without eliciting any discomfort to the underlying brain. The electric current produced by this particular field serves to stimulate the neurons in the human brain.

The spatial resolution of magnetic resonance imaging (MRI) can vary depending on factors such as the form of coil employed, the dissemination of CSF (cerebrospinal fluid), and additional relevant considerations. This resolution may range from centimeters to millimeters. Given that the method is generating activity rather than quantifying it, it is imperative to reconsider the temporal resolution. The duration required for stimulus delivery is comparable to the rate of neuronal firing. Various methods of delivering stimulation are available, including a single pulse, paired pulses targeting the same or different brain regions, or repeated pulses. Bai, Zhang, and Fong [13] have the ability to investigate the effects of modulating cortical excitability on various brain regions, circuits, and behaviors due to the adjustable nature of pulse intensity. Possible outcome measures include electromyographic feedbacks in the focused muscles, observable movements, patient records (including reports of modest visual percepts, or phosphenes, with activation of the occipital cortex), and task performance disruption. The interruption of task performance happens whenever a stimulation of low frequency is administered shortly before or during the execution of the task, hence affecting the typical operations of the brain region beneath the coil.

One primary limitation linked to this technique is its dependence on direct stimulation of the brain, which carries a minor yet noteworthy potential for inducing seizures. Hence, the presence of adequately trained investigators who conduct comprehensive screening of their subjects is imperative. Repetitive transcranial magnetic stimulation (TMS) is currently under investigation as a diagnostic modality for different neurological disorders, encompassing paralysis, depression, tremors, bradykinesia, spasticity, and stroke.

Magnetic resonance imaging

Certain atomic nuclei, such as hydrogen-1 (1H), sodium-23 (23Na), carbon-13 (13C), phosphorus-31 (31P), and others, possess a nuclear magnetic moment or "spin" due to their possession of spin angular momentum. Although there are several nuclei that can generate an MR signal, only the hydrogen nuclei (1H) found in liquid water produce a sufficiently robust signal to render MRI a feasible method for investigating sediments. A result of subjecting materials with a high concentration of hydrogen-1 (1H) to a stationary magnetic field (as depicted in **Fig 4**), denoted as B0, is the generation of a magnetization that is oriented at a right angle to the field's direction. At the Larmor Frequency, the net magnetization exhibits rotational motion around the stationary magnetic field and undergoes the process of radio frequency radiation absorption and emission. Brief bursts of radio frequency (RF) radiation are employed to stimulate the nuclear spins, causing the overall magnetization to shift perpendicular to the main magnetic field (B0). This is achieved by utilizing an RF coil (as depicted in **Fig 4**) that is tuned to resonate at the Larmor frequency. The magnetic resonance (MR) signal is produced through the induction of alternating current in the radiofrequency (RF) coil, which occurs as a result of the precession of the transverse magnetization.

Furthermore, the spatial position of the nuclei within the sample can be identified by implementing magnetic field gradient coils (see **Fig 4**) to induce a linear variation in the magnetic field. This variation leads to precession of the nuclei at slightly distinct frequencies at different locations across the sample. A relaxation weighted image is generated when the net magnetization returns to equilibrium following an RF pulse. The decay of transverse magnetization, as quantified by T2 transverse relaxation, occurs concurrently with the recovery of longitudinal magnetization, as quantified by T1 longitudinal relaxation. The occurrence of T1 and T2 relaxation is observed when fluid molecules are in close proximity to the surface of the pore. In this context, the relaxation time is directly proportional to the size of the pore. The T2 relaxation at higher magnetic fields (>10MHz) is significantly affected by fluid molecules diffusion over internal magnetic field gradients, which arise from the magnetic vulnerability variation between the fluid and solid. The employment of paramagnetic contrast agents enables the observation of fluid-related transport phenomena within porous media over time by reducing the relaxation durations.

Pulse Field Gradient (PFG) imaging is a magnetic resonance imaging (MRI) technique that offers an alternative approach to investigate the movement of fluids. PFGs utilize a pair of magnetic field gradient pulses to encode information about the displacements of molecules. This encoding enables the determination of various parameters such as diffusion, dispersion, and velocity. Individuals with a desire to expand their knowledge regarding the physics underlying the aforementioned images and the overarching principles of Nuclear Magnetic Resonance (NMR) are encouraged to consult the works of Krivdin [14].

In contrast to alternative imaging modalities, MRI does not expose patients to an ionizing radiation, as it utilizes robust magnetic fields to produce visual representations of living tissues. MRI can be employed to investigate various atoms such as hydrogen, phosphorus, carbon, and sodium. The hydrogen atoms that are bonded to water molecules hold significant relevance in both functional imaging and anatomical imaging. The MRI scanner produces a stationary magnetic field, which is quantified in Tesla units. In contrast, the Earth's magnetic field has a magnitude of approximately 0.00005 Tesla (T). Typically, MRI scanners with magnetic fields ranging from 1.5 T to 3 T are utilized for structural MRI. The imaging device utilizes a pulse sequence consisting of magnetic field gradients with varying intensities and oscillating electromagnetic fields that are specifically calibrated to the properties of hydrogen nuclei in order to generate images.

Pulse sequences have the ability to differentiate between tumors, ligaments, and white and gray matter within the brain by analyzing the concentration and surrounding conditions of hydrogen nuclei present in these tissue types. To comprehend this process, it is essential to possess a foundational understanding of fundamental concepts in physics. A molecule of water integrates two atoms of hydrogen and a single atom of oxygen. The hydrogen atom integrates 1 proton, which possesses a property known as spin. This spin causes the proton to function as a minuscule magnet, emitting its own magnetic signal. In a conventional scenario, the protons exhibit diverse orientations, resulting in the absence of a collective magnetic field. Upon entering the MRI magnetic field of the machine, the human body protons align with the outer magnetic field, as it remains consistently active. This alignment leads to the establishment of a net internal magnetic field.

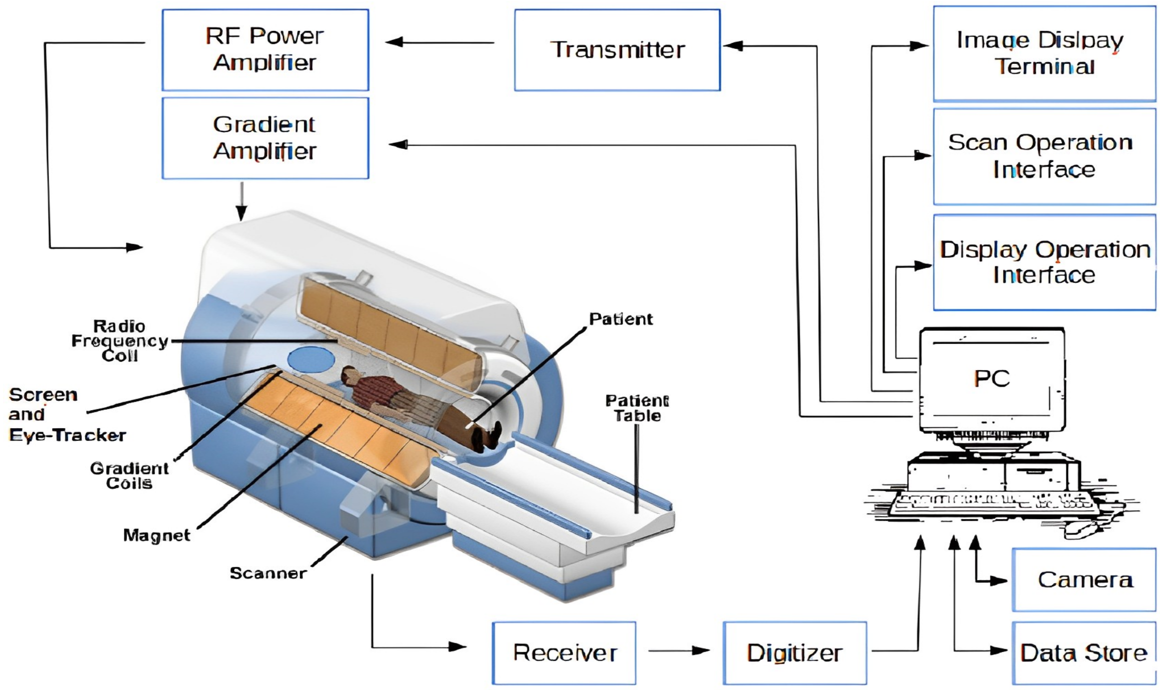

Fig 4. An MRI machine's coils (360 degrees) and magnet are arranged in a concentric pattern

When a radiofrequency (RF) pulse is introduced as a second external magnetic field, the protons within a magnetic resonance imaging (MRI) system exhibit a wobbling motion akin to that of a spinning top. The act of shaking induces a magnetic field that fluctuates over time, resulting in the rotation of said field. Consequently, this rotational motion generates an electric current within the receiver. The aforementioned signal is utilized for the purpose of generating a visual representation. Following the cessation of the radiofrequency (RF) pulse, the protons undergo a gradual process of realignment. The two proton relaxation processes that are commonly assessed in magnetic resonance imaging (MRI) are T1 and T2. These processes are characterized by time constants.

The aforementioned processes occurred when the protons return to their lowest energy state subsequent to the conclusion of the radiofrequency (RF) pulse. T1-weighted imaging is capable of detecting the realignment of a tipped proton with the initial magnetic field, resulting in the restoration of the proton's original orientation. The utilization of relaxation time allows for the differentiation between grey and white matter, as it is affected by the non-excited molecules available within the surrounding tissue. The main objective of a T2-weighted image is to examine the phenomenon of the "falling out" or synchronization dephasing among the oscillating protons. Prompt dephasing arises from the expeditious dissipation of energy within rotating nuclei, and its manifestation is contingent upon the magnet quality. The temporal constants serve as the fundamental basis for discerning between healthy and diseased tissues, exhibiting variations across various tissue environments like blood vessels and grey matter.

Various MRI acquirement methodologies can be employed to produce functional maps, in addition to the conventional MRI technique, which is valuable for disease diagnosis and injury assessment. Functional maps can be generated by considering regional variations in cerebral blood volume, tissue perfusion, or the ratio of deoxygenated hemoglobin to oxygenated hemoglobin resultant from neural activities. These maps illustrate the brain activity that takes place in awake individuals who are engaged in tasks. This article primarily examines the blood-oxygen level-dependent (BOLD) contrast, as the other two methods have not been widely applied in functional imaging researches. The fluctuating functional magnetic resonance imaging (fMRI) signal can be attributed to this phenomenon. The imaging technique known as magnetic resonance imaging (MRI) relies on T2 weighting, incorporating an additional factor to accommodate the magnetic field's lack of uniformity, hence the designation "T2* weighting."

IV. ADVANTAGES AND LIMITATIONS OFNEUROIMAGING TECHNIQUES

The field of neuroscience has been greatly advanced by neuro-psychological investigations conducted in humans and lesion studies performed in animals. These studies have provided valuable insights into the specific functions and contributions of different brain regions. A significant constraint associated with neuroimaging techniques is their inability to establish causality between a specific cognitive activity and the necessity of a particular brain region, a capability possessed by neuropsychological and lesion-based methodologies. Neuroimaging investigations, nevertheless, demonstrate that cognitively normal adults frequently engage this region in order to accomplish the task. Increased activation of this particular region is positively correlated with enhanced task performance, and the degree of activation can be compared among individuals. Moreover, it is possible to compare activation levels within an individual subject's trials, enabling us to establish that activation was diminished in this particular region during trials where the subject committed an error as opposed to trials where the subject achieved success. Hence, the involvement of a specific region of the brain in a particular cognitive task can be assessed by employing functional brain imaging techniques.

Transcranial magnetic stimulation (TMS) is a technology that has the potential to be employed alongside brain imaging techniques to selectively and temporarily disrupt neuronal activity with high precision in both time and space. Neuroimaging techniques offer a multitude of substantial advantages compared to neuropsychological methods. Firstly, while neuroimaging inquiries may focus on cognitive processes that precede or are unrelated to a behavioral response, neuropsychological investigations necessitate the use of behavioral outcomes as the essential dependent variable. The relationship between lesions impacting long-term memory and potential difficulties in encoding and/or retrieval remains uncertain. Nevertheless, the utilization of brain imaging techniques enables the identification of discrete cerebral regions associated with the effective encoding and retrieval of memories.

Furthermore, with the utilization of neuroimaging technology, it has become possible to ascertain the comprehensive neural circuitry that underlies a cognitive process. The process of conducting animal lesion studies involves a sequential approach, wherein individual regions are lesioned one at a time. Due to the limited availability of individuals exhibiting the requisite brain injuries, the pursuit of this objective in human neuropsychological research would encounter significant challenges. The significance of this factor is of utmost importance, as the impact of a specific region on cognitive functioning could potentially be disregarded or inaccurately assessed in studies involving brain lesions. The hippocampus, for example, has long been regarded as a crucial element in the processes of memory formation and retrieval.

Neuroimaging research has demonstrated that the prefrontal cortex constantly plays a role in both the encoding and retrieval of memories in individuals with normal brain function. The field of memory research has witnessed substantial progress as a result of advancements in neuroimaging techniques. Research on the long-term storage of semantic memory has begun to unveil the intrinsic organization of information within the brain during periods of inactivity. The research presented demonstrates that discrete attributes of an object are encoded in separate regions of the brain. An illustration of this can be seen in the brain's organization, where details pertaining to the visual appearance of an object are stored within a specific region responsible for form processing.

Conversely, information regarding the object's functionality is localized near a brain region responsible for motion processing. Through studies on memory encoding, researchers have successfully identified specific brain regions whose levels of activity during stimulus processing can accurately predict subsequent memory retention for that particular stimulus. Research on memory retrieval is also being utilized to resolve the debate between different models of episodic memory. These models propose that recollection, which involves the ability to vividly recall an item and the context in which it was previously encountered, and familiarity, which refers to a general sense of having encountered the item before, are either separate cognitive processes or exist on a spectrum of memory retrieval. The aforementioned case studies serve as exemplars showcasing the efficacy of brain imaging research in the assessment of contrasting psychological theories.

Moreover, in the absence of access to specific patient cohorts, the utilization of neuroimaging techniques enables the examination of cognitive processes associated with a particular region of the human brain, thereby compensating for the limited availability of neuropsychological patients. Moreover, the majority of brain lesions exhibit a relatively large size, thereby posing significant challenges (potentially rendering it unfeasible, contingent upon the specific brain region) in identifying patients with lesions specifically localized to the region of interest. The phenomenon of cortical reconfiguration over time can lead to the mistaken belief that a previously damaged brain area is not typically involved in a specific cognitive task, as the recovery of function can occur.

In conclusion, high-temporal-resolution neuroimaging techniques such as electroencephalography (EEG) and magnetoencephalography (MEG) offer significant contributions to our understanding of brain functioning. By establishing the temporal sequence in which brain area X becomes active subsequent to region Y, we can achieve a better understanding of the sequential progression of processes that culminate in memory retrieval. This approach offers greater utility compared to a mere assertion that brain regions X and Y are implicated in memory retrieval.

Critiques of neuroimaging research frequently center around its dearth of a robust theoretical framework. Nevertheless, the utilization of brain imaging can vary in its efficacy, similar to other scientific methodologies. The domain of brain imaging has witnessed a considerable number of preliminary inquiries, particularly during its initial stages when it was imperative to validate the novel techniques. The subsequent phase of imaging investigations, commencing in the latter part of the 1990s, has exhibited a more focused and specific approach [15]. Cognitive neuroscientists typically employ meticulous experimental manipulations to examine specific hypotheses pertaining to brain function or psychological concepts. Brain imaging techniques are expected to continue playing a significant role in the field of cognitive neuroscience in the coming years.

V. CONCLUSIONS

Extensive investigations conducted over several decades in the field of brain imaging and neuroscience have resulted in significant insights into the fundamental aspects of human perception, cognition, and behavior within real-world settings. Nevertheless, it is argued that there may be notable differences between human behavior observed in laboratory settings and that exhibited in real-world contexts. The extent to which our comprehension of the functioning of the brain can be successfully applied to the highly dynamic real world remains uncertain. Although there have been notable successes in the application of neurotechnologies, particularly in the field of brain-computer interface technologies, progress and innovations in this area have thus far been limited to a specific subset of the scientific and technological community. Neuroimaging studies have contributed to a more comprehensive understanding of the neural underpinnings of various cognitive abilities, including attention, language, and memory.

Neuroimaging techniques have also been employed for evaluating functional recovery following brain injury, facilitating surgical planning, and elucidating the etiology of neurobehavioral disorders. The field of memory research has experienced notable progress as a result of advancements in neuroimaging techniques. Research on long-term semantic memory has provided novel insights into the mechanisms by which the brain encodes and retrieves information. The conducted experiments provide evidence that the brain stores information pertaining to multiple properties of an object in different regions. Specifically, visual form information is stored in a brain region specialized in form processing, while functional information is stored in proximity to a brain area responsible for motion processing. Research on memory encoding has also identified specific brain regions that exhibit activity during stimulus processing, which can predict the memory recall of that information in the future.

Data Availability
No data was used to support this study.

Conflicts of Interests
The author(s) declare(s) that they have no conflicts of interest.

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Ethics Approval and Consent to Participate
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Competing Interests
There are no competing interests.

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