Using Motor Imaging and Deep Neural Networks for Knee Osteoarthritis (OA) Diagnosis: A State-of-the-Art Approach

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Knee osteoarthritis is a degenerative condition affecting the knee joints. It occurs when the cartilage covering the joint surfaces of the knee progressively wears away, leading to pain, swelling, stiffness, and loss of function in the affected knee. Cartilage, a smooth and tough tissue, is a shock absorber between bones and enables smooth joint movement. With time, factors such as aging, overuse, or prior injuries can contribute to cartilage deterioration, thus increasing the risk of knee osteoarthritis development. Accurately diagnosing knee osteoarthritis (OA) can be time-consuming, given that several other conditions share similar signs and symptoms. This study aims to expedite the diagnosis of knee OA by leveraging motor imagery patterns detected through electroencephalogram (EEG) analysis using deep learning techniques.
Keywords: Knee Osteoarthritis. Motor Imaging. Electroencephalogram (EEG). Deep Gearning.

The primary risk factors for developing knee osteoarthritis (OA) encompass aging, a family history of the disease, previous joint injuries, obesity, excessive or inadequate physical activity, and certain medical conditions like rheumatoid arthritis. Symptoms of knee osteoarthritis can vary, including pain exacerbated by physical activity, swelling, stiffness, crepitus (creaking or popping) during knee movement, muscle weakness, and limited range of motion. Over time, knee OA can significantly impact quality of life, impairing everyday activities such as walking and stair climbing. Diagnosis typically involves a comprehensive clinical examination, detailed medical history review, X-rays, and, occasionally, other imaging tests such as MRI [1].

The primary objective of this study is to explore, develop, and assess a diagnostic tool utilizing motor imagery and deep neural networks (deep learning) for knee OA diagnosis. Specific aims include digitizing, studying, and organizing EEG databases of individuals with and without OA pathology into a user-friendly format. Subsequently, the study aims to create and simulate a model representing the system and, ultimately, to test, evaluate, refine, and assess the accuracy of the proposed model for OA diagnosis. Recent research suggests that electroencephalography (EEG) is emerging as a potential tool for chronic pain analysis, particularly in rheumatic diseases like osteoarthritis. Studies conducted by Pinheiro and colleagues (2016) [2] indicate that evaluating EEG characteristics during wakefulness, a period of complete rest, reveals EEG slowness associated with chronic neuropathic pain. Additionally, theta and alpha bands exhibit higher absolute density in patients with chronic pain than in healthy individuals, suggesting discernible patterns that can be used for diagnostic purposes.

Further investigations, such as the study by Luft & Andrade (2006) [3], delve into motor imagery, the mental visualization of movement without actual muscle activation, captured via EEG. Their findings demonstrate cortical activation in pre-motor and motor brain areas during motor imagery, offering a non-invasive means to diagnose severe pain in structures like skeletal muscles without inducing movements that could exacerbate the issue.

Building upon these studies, we propose the following hypothesis: Can artificial intelligence classification techniques identify patterns in EEG

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signals of individuals with knee osteoarthritis solely through motor imagery of contraction and relaxation in the affected area?

Given the significance of technologies facilitating early disease diagnosis and the economic and social importance of studies in this field, this research aims to enable diagnosis through comparative analysis. Specifically, it seeks to establish a model to estimate the probability of knee osteoarthritis (OA) based on electroencephalogram (EEG) signal patterns and motor imagery in groups of individuals with and without the condition.

Materials and Methods

The electroencephalogram (EEG) records the brain's electrical activities over time. These activities generate low-intensity fields captured and recorded by electrodes placed on the scalp. Protocols have been developed to standardize electrode placement for EEG signal capture. In this study, the International 10-20 System protocol was employed. This protocol utilizes 20 points marked on the skull, dividing it into proportions of 10% or 20% of the distances between reference points: Nasion and Inion in the medial plane (Figure 1a) and pre-auricular points in the perpendicular plane to the skull (Figure 1b) [4].

The lobe beneath each electrode is identified by a nomenclature consisting of a maximum of two letters and a number or another letter to identify its hemispheric position [5]. Table 1 details each point of the electrodes.

The data has been digitized, processed, and formatted into spreadsheets at this research stage. Each file has been appropriately tagged for submission to the deep neural network (deep learning) CNN, which is currently under development. Regarding hardware and software, the research employs an I7 processor with 64 GB of RAM and an RTX 4070 TI graphics card (GPU) with 12 GB of RAM, utilizing a 7680 CUDA 192-bit GDDR X type. The software utilized includes Matlab, the Anaconda platform with Python, and its libraries, such as Tensorflow and Keras.

Theoretical Framework

To identify gaps in the intersection of knee osteoarthritis (OA) and deep learning, a comprehensive search was conducted on Google Scholar using keywords such as "Knee Osteoarthritis," "Deep Learning," and "Convolutional Neural Network." Initially, the search yielded 751 articles, and upon adding "motor imagery" to the search terms, no relevant results were found. From the initial search, three significant articles were selected as the basis for the research. Table 2 provides a summary of these critical articles.

Therefore, the decision was made to further explore the research on knee osteoarthritis (OA) through motor imagery, which emerged as a notable gap in this study.

Conclusion

We aim to present a model capable of diagnosing the pathology of osteoarthritis (OA) with a high level of probability using a patient's EEG data.

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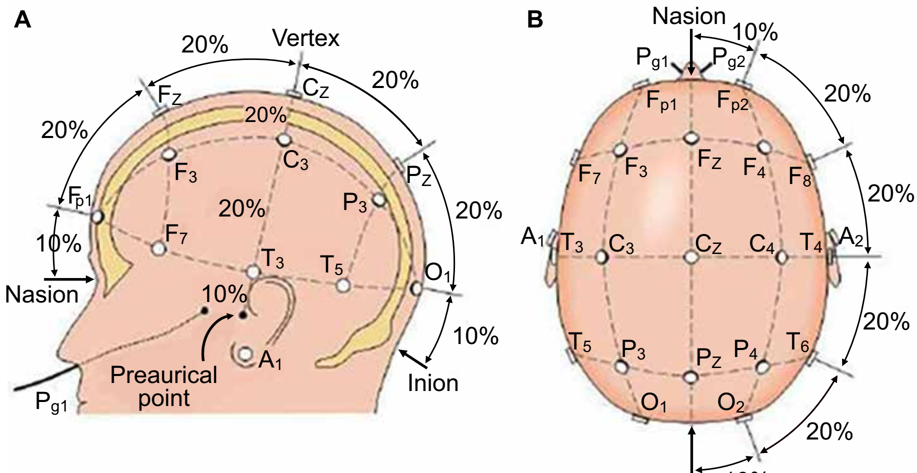
Table 1. Points in the 10-20 pattern.

Points	Represented Area
Fp	Frontal polar
F	Frontal
T	Temporal
C	Central
P	Parietal
O	Occipital
z	Midline
Numbers	Odd numbers on the left side of the midline, even numbers

Figure 1. Different perspectives of the international standard 10-20 for electrode positioning.



Source: Fu and colleagues (2006) [4]

Table 2. Relevant articles.

Publication	Year	Method
Knee osteoarthritis severity prediction using an attentive multi-scale deep convolutional neural network [6]	2024	X-ray analysis through CNN
Emergence of deep learning in knee osteoarthritis diagnosis [7]	2021	Using of 2D and 3D magnetic resonance imaging with DL
Imaging studies on OA research between January 2019 and April 2020: models of early knee OA, structure modification in established OA, deep learning approaches in image analysis [8]	2021	MRI, X-ray (plain radiography)

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