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EDITORIAL

The Role of Artificial Intelligence in Neurology: Transformations and Challenges

Marleide da Mota Gomes
mmotagomes@acd.ufrj.br

Modern life has been significantly impacted by artificial intelligence (AI), with machine learning (ML) acting as a key technology that has fueled numerous breakthroughs. These data-driven models enable systems to learn and adapt by processing vast datasets, significantly enhancing functionality. In neurology, deep learning has become a cornerstone of research and innovation, particularly as data complexity continues to grow. This transformative potential was highlighted by the 2024 Nobel Prize in Physics, awarded to John Hopfield and Geoffrey Hinton for their pioneering contributions to ML and artificial neural networks.[9]

Hopfield's seminal 1982 work revolutionized associative memory by developing networks capable of efficiently storing and retrieving information despite noise or missing inputs. These networks simulated neural connections in the brain, allowing AI systems to process and correct distorted information in a manner analogous to human memory. Building on this foundation, Hinton's 1985 Boltzmann machine introduced the use of statistical physics to analyze patterns. Hinton's later advancements in deep learning have enabled computers to autonomously learn from extensive datasets, leading to applications in areas such as recommendation systems and image recognition.[9]

The evolution of ML algorithms spans from traditional statistical methods to advanced deep learning models.[1] Before 2006, ML primarily utilized superficial techniques like decision trees and single-layer neural networks. However, the advent of deep learning, particularly through multilayered architectures such as Convolutional and Recurrent Neural Networks, has dramatically enhanced ML's capacity to address complex medical challenges. These innovations have proven especially valuable in diagnostics and the analysis of diverse data types, including EEG signals and medical imaging.[10]

Generative AI (GAI) has emerged as a transformative tool in content creation, encompassing audio, image, text generation, and research applications.[1,3] Large language models (LLMs), such as GPT-4, extend AI's potential beyond automation by processing vast datasets, deriving meaningful insights, and supporting clinical decision-making. For instance, Romano et al. demonstrate LLMs' capabilities, including passing the U.S. Medical Licensing Examination, underscoring their potential in neurology.[4]

The varied definitions of AI often lead to confusion. Sheikh et al. address this issue by noting that limiting AI to algorithms or human-like intelligence overlooks its broader scope.[7] They propose defining AI as autonomous systems or technologies mimicking advanced human abilities, a perspective that aligns with explorations of human cognition. This perspective is reinforced by Moravec's paradox, which highlights AI's proficiency in complex tasks while struggling with basic human functions.

AI's development has progressed through three distinct waves. The first wave, marked by the 1956 Dartmouth Summer Research Project, focused on games and problem-solving but eventually led to an "AI winter" due to unmet expectations. The second wave, centered on expert systems in the 1980s, also waned. The third wave, beginning in the 1990s, brought transformative advancements in deep learning and neural networks, exemplified by IBM's Deep Blue defeating a chess champion. This cyclical pattern of progress and setbacks illustrates AI's evolving potential.[7]

AI's transformative role in neurology is evident in its applications for diagnosing and treating neurological disorders. Kalani and Anjankar, along with Voigtlaender et al., and others emphasize its contributions to diagnostics, disease modeling, and neurorehabilitation.[1,2,10] By analyzing extensive datasets, such as genetic and imaging data, AI facilitates early diagnosis and personalized treatment, identifying subtle patterns in conditions like brain tumors and strokes. In neuroimaging, AI automates anomaly detection and brain structure analysis, reducing radiologists' workloads while improving diagnostic accuracy.[2]

Radiomics, a field that extracts high-dimensional features from medical images, is revolutionizing neuroimaging by aiding in stroke lesion detection, vessel occlusion analysis, and biomarker identification. In neuro-oncology, radiomics enables the prediction of molecular profiles, such as isocitrate dehydrogenase mutations in gliomas through MRI. However, broader clinical adoption requires further validation.[10]

Shah and Heiss highlight AI's value in managing complex cases, such as stroke and epilepsy, by identifying patterns often overlooked by humans.[6] AI's influence extends to patient monitoring, treatment planning, and diagnosis, facilitating early detection and tailored interventions. Wearable devices powered by AI monitor vital signs, identify at-risk individuals, and provide actionable recommendations. These technologies enable real-time health monitoring, improving outcomes while minimizing side effects.

Neurorehabilitation also benefits from AI innovations, such as neuroprosthetics and brain-machine interfaces, which aid in restoring cognitive and motor functions. AI-driven advancements in radiomics further enhance therapy guidance and biomarker identification. Additionally, AI is transforming medical education by providing realistic simulations that foster critical thinking and equip future neurologists with skills for data-driven healthcare.[8] AI-powered tools also enable performance analysis, remote learning, and personalized instruction, breaking geographic barriers and promoting diversity in education.

To fully realize AI's potential in neurology, it is essential to address ethical considerations, data privacy, algorithmic biases, and contextual understanding. Neurologists play a critical role in guiding AI's ethical development and ensuring its responsible integration into healthcare. Rather than replacing clinicians, AI should complement their expertise by automating specific tasks while preserving the focus on patient-specific characteristics.[5]

While AI technologies enhance patient outcomes and support precision medicine, the empathy and expertise of physicians remain indispensable. By embracing AI, neurologists can sustain a competitive edge in the evolving healthcare landscape and continue to deliver compassionate, high-quality care.

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