The role of neurovisualization in monitoring stroke risk among athletes: a review

El papel de la neurovisualización en el monitoreo del riesgo de ictus en atletas: una revisión

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Abstract

Introduction: this study addressed the emerging role of neurovisualization in assessing and mitigating stroke risk among athletes, a population increasingly exposed to neurovascular stress due to intense physical activity. the subject gained relevance with the growing recognition of subclinical cerebrovascular changes in sports contexts.
Objective: the objective of the research was to explore the integration of advanced neuroimaging techniques and artificial intelligence to enhance early detection, longitudinal monitoring, and risk prediction of cerebrovascular events in athletic populations.
Methodology: a systematic literature review was conducted, focusing on studies that applied functional magnetic resonance imaging, diffusion tensor imaging, computed tomography angiography, and other modalities in combination with predictive analytics and machine learning models. inclusion criteria were applied to filter relevant research involving athletes and cerebrovascular monitoring.
Results: the main results indicated that imaging biomarkers such as microbleeds, perfusion deficits, and white matter disruptions could be effectively detected and interpreted using artificial intelligence models. wearable data integrated with neuroimaging further enhanced the precision of predictive assessments.
Discussion: the findings were consistent with previous studies that supported the use of multimodal imaging and computational tools in stroke risk evaluation. however, data heterogeneity and algorithmic transparency were identified as persistent challenges across the reviewed literature.
Conclusions: It is concluded that the integration of neurovisualization with predictive analytics offers a promising framework for proactive brain health management in athletes and should be further developed and standardized in clinical practice.

Keywords

Neurovisualization; stroke; athletes; artificial intelligence; imaging biomarkers.

Resumen

Introducción: este estudio abordó el papel emergente de la neurovisualización en la evaluación y mitigación del riesgo de ictus en atletas, una población cada vez más expuesta al estrés neurovascular debido a la actividad física intensa. el tema cobró relevancia con el creciente reconocimiento de cambios cerebrovasculares subclínicos en contextos deportivos.
Objetivo: el objetivo de la investigación fue explorar la integración de técnicas avanzadas de neuroimagen e inteligencia artificial para mejorar la detección temprana, el monitoreo longitudinal y la predicción del riesgo de eventos cerebrovasculares en poblaciones atléticas..
Metodología: se realizó una revisión sistemática de la literatura, centrándose en estudios que aplicaron resonancia magnética funcional, imagen por tensor de difusión, angiografía por tomografía computarizada y otras modalidades en combinación con análisis predictivos y modelos de aprendizaje automático. se aplicaron criterios de inclusión para filtrar investigaciones relevantes que involucraran a atletas y monitoreo cerebrovascular.
Resultados: los principales resultados indicaron que biomarcadores de imagen como microhemorragias, déficits de perfusión y alteraciones de la sustancia blanca podían ser detectados e interpretados eficazmente mediante modelos de inteligencia artificial. los datos de dispositivos portátiles integrados con neuroimagen mejoraron aún más la precisión de las evaluaciones predictivas.
Discusión: los hallazgos fueron consistentes con estudios previos que respaldaron el uso de imágenes multimodales y herramientas computacionales en la evaluación del riesgo de ictus. sin embargo, la heterogeneidad de los datos y la transparencia algorítmica se identificaron como desafíos persistentes en la literatura revisada.
Conclusiones: se concluye que la integración de la neurovisualización con análisis predictivos ofrece un marco prometedor para la gestión proactiva de la salud cerebral en atletas y debe seguir desarrollándose y estandarizándose en la práctica clínica.

Palabras clave

Neurovisualización; ictus; atletas; inteligencia artificial; biomarcadores de imagen.

Introduction

Stroke remains a leading cause of death and long-term disability worldwide, traditionally associated with elderly populations and individuals with cardiovascular comorbidities such as hypertension, diabetes, and atherosclerosis. However, recent studies have highlighted that stroke can also affect younger, seemingly healthy populations, including competitive athletes, under specific physiological conditions (Singh et al., 2024). Although rare, ischemic strokes in athletes may result from mechanisms such as arterial dissection, hyperviscosity induced by dehydration, or embolic events triggered by extreme exertion (Matsulevits et al., 2024). These cerebrovascular events, despite their low incidence, carry profound medical and career-threatening implications, reinforcing the need for proactive monitoring and early detection strategies in high-risk athletic groups.

Neurovisualization is a term encompassing advanced brain imaging techniques such as magnetic resonance imaging (MRI), functional MRI (fMRI), computed tomography angiography (CTA), and diffusion tensor imaging (DTI) has profoundly transformed the capacity to understand cerebrovascular pathophysiology (Dobrynina et al., 2022). These modalities enable the detection of subtle neurovascular changes, including cerebral perfusion deficits, vascular wall integrity alterations, and early neurodegenerative markers that often precede clinical symptoms (Mukhammadjonov et al., 2025). For athletes, particularly those exposed to intense physical loads, these diagnostic tools provide critical opportunities for the identification of silent microinfarcts, white matter changes, and other preclinical cerebrovascular anomalies (Polamuri et al., 2024).

The relationship between physical activity and neurovascular health is paradoxical. While moderate exercise exerts neuroprotective effects by enhancing vascular function, promoting endothelial health, and reducing systemic inflammation (Alekseeva et al., 2024), excessive or extreme training, particularly in endurance sports, may increase transient blood pressure peaks and mechanical stress on arterial walls (Alekseeva et al., 2024). Such physiological stressors can precipitate vascular injury or exacerbate underlying vulnerabilities. Therefore, individualized cerebrovascular risk assessment incorporating imaging biomarkers becomes indispensable. Neurovisualization facilitates this assessment, supporting both acute diagnostic needs and longitudinal monitoring across athletic training cycles (Enyagina et al., 2022).

Recent advancements in artificial intelligence (AI) and machine learning have enhanced the interpretive power of neuroimaging, enabling the detection of subtle anomalies that may not be evident through conventional analysis. These AI-driven models offer new possibilities for stratifying stroke risk and tailoring preventive interventions in sports medicine (Kalashnikova, 2022). Furthermore, integrating neuroimaging data with wearable physiological monitoring systems opens a promising avenue for real-time cerebrovascular assessment, particularly in high-performance settings (Huang et al., 2023).

Despite technological advances, the implementation of neurovisualization in athletic populations remains limited and fragmented. The majority of neuroimaging studies have focused on elderly patients or post-stroke rehabilitation cohorts, leaving a notable gap in evidence related to asymptomatic athletes (van Voorst et al., 2023). Additionally, the absence of standardized imaging protocols in sports medicine hampers the consistent application of these diagnostic tools (Lavrentev et al., 2024).

This review aims to explore the current state of knowledge on the role of neurovisualization in assessing and monitoring stroke risk among athletes (Population), focusing on advanced imaging modalities and their integration with predictive analytics (Concept) within the context of sports medicine and cerebrovascular prevention (Context). The specific objectives are:

(1) To analyze the pathophysiological mechanisms underlying stroke risk in athletes;

(2) To examine the application of neurovisualization techniques in risk detection and monitoring;

(3) To evaluate the role of AI-driven imaging analytics in enhancing diagnostic precision;

(4) To identify research gaps and propose future directions for clinical application in athlete health management.

This review addresses a critical gap by synthesizing current evidence on the application of neurovisualization for stroke risk monitoring in athletes, integrating imaging modalities with emerging AI technologies. By consolidating findings across clinical studies, technological advancements, and sports medicine contexts, the review seeks to inform future research and support the development of standardized screening protocols. Ultimately, it underscores the importance of proactive cerebrovascular monitoring to enhance both the safety and performance of athletes at risk.

Methodology

The methodology employed in this review is grounded in a systematic and integrative approach to identifying, evaluating, and synthesizing current research on the role of neurovisualization in monitoring stroke risk among athletes. A comprehensive literature search was conducted across multiple scientific databases, including PubMed, Scopus, and Web of Science, focusing on peer-reviewed articles published in the last two decades. Keywords such as "neuroimaging," "stroke risk," "athletes," "cerebral perfusion," and "artificial intelligence in neurovisualization" were used to ensure relevance and coverage. Inclusion and exclusion criteria were defined to filter for studies that specifically addressed imaging techniques, cerebrovascular monitoring, and AI-based predictive models in athletic populations. The selected studies were then analyzed to extract data on imaging modalities, biomarkers, technological integration, and clinical applications. This structured approach allowed for the identification of prevailing trends, methodological innovations, and knowledge gaps in the field, laying a strong foundation for the discussion and future research recommendations presented in this paper.

Search Strategy

A comprehensive literature search was performed across several major academic databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, PubMed, and Medline, to ensure the inclusion of high-quality peer-reviewed journal articles published within the last ten years. The search strategy was designed to capture studies at the intersection of stroke diagnosis, athletic health, neurovisualization techniques, and applications of artificial intelligence. A combination of keywords such as “stroke,” “athlete,” “neurovisualization,” and “artificial intelligence” was employed, utilizing Boolean operators (AND, OR) to optimize the retrieval of relevant records. Additionally, the reference lists of all selected articles were manually reviewed to identify further studies that met the inclusion criteria and contributed valuable insights to the research topic.

Inclusion and Exclusion Criteria

The selection of studies for this review was guided by well-defined inclusion and exclusion criteria to ensure the relevance and quality of the analyzed literature. As summarized in Table 1, only peer-reviewed research and review articles directly addressing the role of neurovisualization in stroke risk assessment, particularly within athletic populations, were included. This approach enabled the incorporation of both empirical evidence and synthesized theoretical frameworks. Articles were excluded if they were duplicates, non-research in nature (e.g., editorials or opinion pieces), or lacked a clear focus on stroke, neuroimaging, or athletic health. Furthermore, studies that were only tangentially related or lacked methodological rigor were omitted to maintain the specificity and validity of the review findings. These criteria provided a robust foundation for identifying the most pertinent and high-quality sources available in the current scientific landscape.

Table 1. Inclusion and Exclusion Criteria for Study Selection

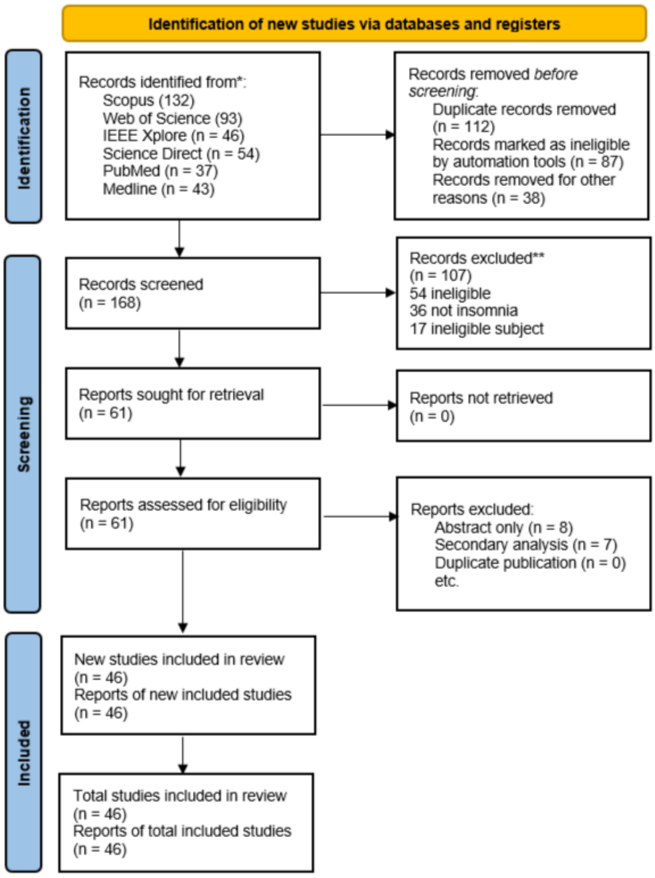
I/E	Criteria	Explanation
Inclusion	Research papers	Empirical studies that present original data or experimental results related to stroke monitoring, imaging techniques, or athletic health risks.
	Review papers	Articles that systematically analyze and synthesize existing literature on neurovisualization, stroke risk, or athlete health.
Exclusion	Duplicated articles	Papers that appear more than once in the dataset or are repeated publications of the same study.
	Non-research articles	Editorials, commentaries, letters to the editor, news articles, or opinion pieces without empirical evidence or systematic methodology.
	Non-related articles	Studies that do not address stroke, athletes, neurovisualization, or relevant intersections.

	Implicitly related articles	Articles that may mention relevant terms but lack a direct focus or substantial content on the topic of interest.
	Non-peer-reviewed sources	Grey literature or articles not published in peer-reviewed scientific journals.

Data Extraction and Synthesis

Following the selection of relevant studies, data extraction was systematically performed using a standardized form to ensure consistency and comprehensiveness. Key information retrieved from each article included authorship, publication year, study design, sample characteristics, type of artificial intelligence methods used, neurovisualization modalities, and primary outcomes related to stroke detection or athlete monitoring. The extracted data were independently verified by multiple reviewers to minimize bias and discrepancies. A narrative synthesis approach was adopted to integrate the findings, identify patterns, and highlight emerging trends across the studies. The synthesis focused on evaluating the effectiveness of AI-driven techniques in enhancing stroke diagnosis and their applicability to athletic populations, while also considering methodological heterogeneity and research gaps.

Figure 1. PRISMA Flow Diagram for Study Selection Process



The methodological approach of this review followed a systematic and structured process designed to ensure comprehensive coverage and selection of relevant studies on the role of neurovisualization in monitoring stroke risk among athletes. A multi-database search strategy was employed, retrieving records from six major scientific repositories: Scopus (n = 132), Web of Science (n = 93), IEEE Xplore (n = 46), ScienceDirect (n = 54), PubMed (n = 37), and Medline (n = 43). This initial identification phase yielded a substantial pool of studies (n = 405), from which records were systematically removed prior to screening based on duplication (n = 112), automation tool ineligibility flags (n = 87), and other exclusionary factors such as irrelevant scope or inappropriate study design (n = 38). Following this filtration, a total of 168 records underwent title and abstract screening, during which 107 articles were excluded for reasons including ineligibility (n = 54), lack of focus on the relevant subject matter (n = 17), or addressing conditions outside the scope of this review, such as studies not pertaining to stroke or neurovisualization in athletes (n = 36). Subsequently, 61 full-text reports were sought for retrieval, all of which were successfully accessed and assessed for eligibility. Of these, 15 reports were excluded for being abstracts only (n = 8), secondary analyses (n = 7), or other methodological limitations. Ultimately, 46 studies met the predefined inclusion criteria and were incorporated into the final synthesis. This selection process is detailed in the PRISMA flow diagram (Figure 1), which illustrates the rigorous screening, assessment, and inclusion phases undertaken to ensure that only high-quality, peer-reviewed studies directly relevant to the research objectives were analyzed. The systematic methodology adopted in this review provides a robust foundation for evaluating current evidence, minimizing bias, and supporting comprehensive analysis of the intersection between neurovisualization, stroke risk, and athletic performance monitoring.

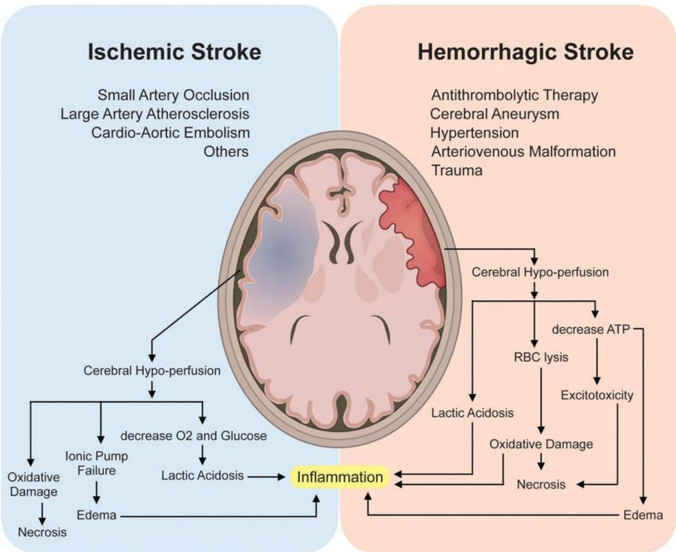
Pathophysiology and Risk Factors of Stroke in Athletes

The pathophysiology of stroke in athletes encompasses both conventional cerebrovascular mechanisms and sport-specific physiological stressors that may precipitate acute neurological events. While the fundamental processes of ischemic and hemorrhagic stroke such as cerebral hypoperfusion, oxidative damage, and inflammation remain consistent across populations, athletes may encounter unique risk factors due to the nature of their physical exertion, vascular strain, and sport-induced trauma.

Ischemic and Hemorrhagic Stroke Mechanisms

As illustrated in Figure 2, ischemic stroke results primarily from a reduction in cerebral blood flow due to vascular obstruction, which may occur through small artery occlusion, large artery atherosclerosis, or cardio-aortic embolism. This cerebral hypo-perfusion leads to a decrease in oxygen and glucose supply, which is critical for maintaining cellular metabolism and homeostasis in neuronal tissues (Yang & Guo, 2024). The resultant energy deficit disrupts ionic pump function, causing intracellular ionic imbalances, edema, and the accumulation of lactic acid. Oxidative damage follows due to the excess generation of reactive oxygen species, ultimately leading to cell necrosis. A key component of the ischemic cascade is the activation of inflammatory responses, which further exacerbate neural injury and hinder recovery processes (Popugaev et al., 2024).

Figure 2. Pathophysiological Mechanisms of Ischemic and Hemorrhagic Stroke (Peng et al., 2022).



Conversely, hemorrhagic stroke is characterized by the rupture of cerebral vessels, often associated with hypertension, aneurysms, trauma, or arteriovenous malformations. As shown in Figure 2, the leakage of blood into the brain parenchyma not only increases intracranial pressure but also induces cerebral hypo-perfusion. This event initiates a cascade of secondary injuries including red blood cell lysis, release of hemoglobin, ATP depletion, and lactic acidosis (Ma et al., 2024). These processes lead to excitotoxicity and oxidative stress, further damaging the surrounding tissue and resulting in necrosis and edema. Inflammatory pathways, common to both ischemic and hemorrhagic mechanisms, play a central role in amplifying neuronal injury and disrupting the blood-brain barrier (Saleem et al., 2024). Understanding these distinct yet overlapping molecular events is essential for the development of targeted therapeutic interventions for both stroke types.

Cardiovascular and Neurovascular Stress in Sports

Intense physical activity, particularly in competitive or endurance sports, imposes substantial stress on both the cardiovascular and neurovascular systems, potentially contributing to acute cerebrovascular events in susceptible individuals. During high-demand exertion, elevated cardiac output, arterial pressure surges, and increased sympathetic nervous system activation may lead to transient endothelial dysfunction, impaired cerebral autoregulation, and heightened neurovascular strain (Omarov et al., 2024; Lin et al., 2024; Sawan et al., 2024). These physiological perturbations, when superimposed on underlying conditions such as hypertension, arrhythmias, or structural vascular abnormalities, can increase the risk of ischemic events due to hypoperfusion and thrombogenesis, or hemorrhagic events due to vessel rupture. Additionally, factors such as dehydration, hyperthermia, and oxidative stress contribute to lactic acidosis and ionic imbalances, mirroring several of the damaging cascades associated with stroke pathophysiology (Yang et al., 2024; Zigmantovich et al., 2021). These interactions underscore the critical need for cardiovascular and neurovascular screening among athletes engaged in high-intensity training and competition.

Sport-Specific Risk Factors

Certain sports are associated with elevated cerebrovascular risk due to their specific physiological demands and mechanical impacts. For example, contact sports such as boxing, American football, and rugby expose athletes to repetitive head trauma, increasing the likelihood of cerebral vessel injury and long-term neurovascular degeneration (Gologush et al., 2021; Koska et al., 2024). Endurance sports like marathon running and cycling, while less traumatic, can induce extreme fluctuations in blood pressure, dehydration, and cardiac strain, all of which may predispose susceptible individuals to ischemic stroke events (Omarov et al., 2024; Karamesinis et al., 2021). Additionally, sports involving sudden exertion or Valsalva-like maneuvers, such as weightlifting and rowing, can cause abrupt increases in intracranial and arterial pressure, potentially triggering hemorrhagic stroke in athletes with undetected aneurysms or arteriovenous malformations (Kim et al., 2024). These sport-specific risks highlight the necessity for individualized screening protocols and targeted preventive strategies in high-risk athletic populations.

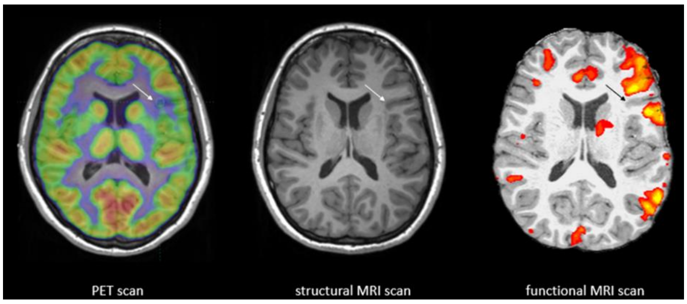
Neurovisualization Techniques in Stroke Risk Assessment

Advancements in neurovisualization techniques have significantly enhanced the ability to assess stroke risk, detect early neuropathological changes, and guide timely interventions. Modern imaging modalities such as magnetic resonance imaging (MRI), computed tomography angiography (CTA), functional MRI (fMRI), diffusion tensor imaging (DTI), and positron emission tomography (PET) offer detailed structural, functional, and metabolic insights into the brain. These technologies enable clinicians and researchers to identify subclinical vascular anomalies, monitor cerebral perfusion, and evaluate microstructural integrity of white matter pathways factors that are critical in understanding individual susceptibility to cerebrovascular events. In the context of sports and high-performance physical activity, neuroimaging serves not only as a diagnostic tool but also as a preventive strategy for detecting asymptomatic lesions, evaluating recovery trajectories, and mitigating long-term neurological risks.

Magnetic Resonance Imaging (MRI) and Functional MRI (fMRI)

Magnetic Resonance Imaging (MRI) and its functional counterpart (fMRI) have become indispensable tools in the diagnosis and monitoring of neurological conditions, including stroke. As shown in Figure 3, structural MRI provides high-resolution images of brain anatomy, allowing clinicians to detect ischemic lesions, hemorrhages, and atrophy with exceptional detail. Functional MRI, on the other hand, captures dynamic changes in brain activity by measuring blood oxygenation level-dependent (BOLD) signals, which are essential for assessing functional impairments and neuroplasticity following stroke events (Zhao et al., 1924; Zhao et al., 2021). The combined use of structural and functional imaging enhances the understanding of stroke-induced alterations in both anatomy and cerebral function, offering a powerful approach for rehabilitation planning and outcome prediction (Smerdov et al., 2021). Moreover, fMRI is particularly valuable in sports medicine for evaluating the neurocognitive consequences of head trauma and repetitive sub-concussive impacts, which may not be apparent on conventional MRI (Ashikuzzaman et al., 2024). Together, these modalities support a more comprehensive neurovisualization strategy in both clinical and athletic populations.

Figure 3. Comparative Brain Imaging Modalities: PET, Structural MRI, and Functional MRI (fMRI).



Computed Tomography Angiography (CTA) and CT Perfusion

Computed Tomography Angiography (CTA) and CT Perfusion (CTP) are pivotal imaging techniques for the rapid assessment of cerebrovascular conditions, particularly in acute stroke settings. CTA provides detailed visualization of the cerebral vasculature, enabling clinicians to identify arterial stenosis, occlusions, aneurysms, and vascular malformations with high spatial resolution (Kim et al., 2021). This modality is especially valuable for guiding therapeutic decisions such as thrombolysis or mechanical thrombectomy by delineating the site and extent of vascular blockage. CT Perfusion complements CTA by quantifying cerebral hemodynamics, including cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT), which are critical for distinguishing between infarct core and ischemic penumbra (Vinogradova et al., 2021). These parameters facilitate early identification of salvageable brain tissue, enhancing the efficacy of time-sensitive interventions (Liu et al., 2024). When used together, CTA and CTP offer a comprehensive approach to acute stroke triage, significantly improving diagnostic accuracy and patient outcomes (Martín Vicario et al., 2024).

Diffusion Tensor Imaging (DTI) and Brain Connectivity

Diffusion Tensor Imaging (DTI) is an advanced MRI technique that enables the visualization and quantification of white matter microstructure by measuring the directional diffusion of water molecules along axonal pathways. This modality is particularly useful in stroke research and sports neurology for assessing axonal integrity, detecting microstructural damage, and mapping brain connectivity networks (Cherevko et al., 2021; Alekseeva et al., 2024). In the context of stroke, DTI provides critical insights into the extent of white matter disruption, which is often associated with post-stroke cognitive and motor deficits. Fractional anisotropy (FA), a key DTI-derived metric, reflects fiber organization and myelination, and reductions in FA have been linked to poor functional recovery and impaired sensorimotor connectivity (Hao et al., 2021). Furthermore, DTI tractography allows for the reconstruction of major white matter tracts, facilitating the exploration of structural connectivity alterations in athletes exposed to repetitive head impacts or concussive injuries (Luo et al., 2024). By capturing subtle and diffuse changes in brain architecture, DTI serves as a valuable biomarker for early detection, prognosis, and rehabilitation planning.

Positron Emission Tomography (PET) and Spectroscopy

Positron Emission Tomography (PET) and magnetic resonance spectroscopy (MRS) are powerful neuroimaging modalities that offer complementary insights into the metabolic and molecular changes associated with cerebrovascular disease and brain injury. PET imaging enables the quantification of regional cerebral glucose metabolism, blood flow, and receptor binding through the use of radiotracers such as ^{18}F-fluorodeoxyglucose (FDG), making it highly effective in detecting areas of hypometabolism or neuronal dysfunction following ischemic or hemorrhagic stroke (Yu et al., 2025; Ince et al., 2025). PET has also been used to monitor neuroinflammation and protein aggregation in athletes exposed to repetitive head trauma, contributing to early diagnosis of chronic traumatic encephalopathy (Nunes et al., 2024). Meanwhile, MRS provides a non-invasive means to assess brain metabolites such as N-acetylaspartate (NAA), choline, and lactate, offering biomarkers of neuronal health, membrane turnover, and anaerobic metabolism, respectively (Gutierrez et al., 2024). Together, PET and MRS enrich the neurodiagnostic landscape by revealing pathophysiological alterations that often precede structural damage, thus facilitating early intervention and monitoring of therapeutic efficacy.

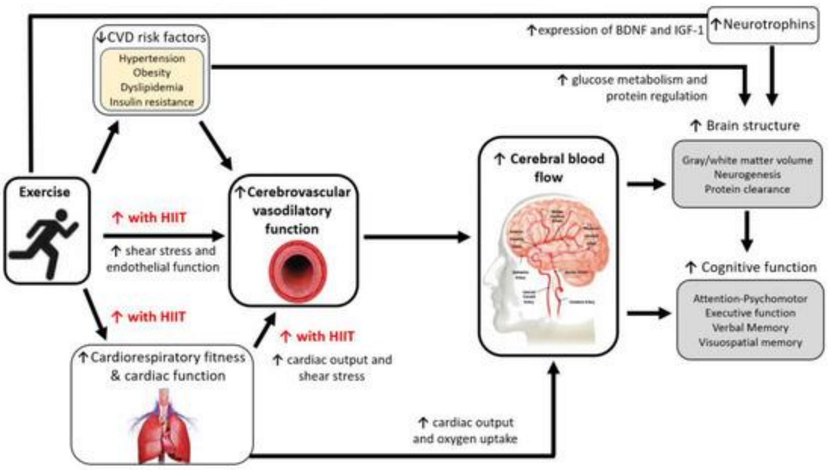
Application of Neurovisualization in Athletes

The application of neurovisualization in athletes has opened new frontiers in sports medicine by enabling the early detection, monitoring, and prevention of neurological impairments associated with intense physical activity. Through the integration of advanced imaging modalities such as functional MRI (fMRI), diffusion tensor imaging (DTI), magnetic resonance spectroscopy (MRS), and perfusion-based techniques, clinicians and researchers can assess brain structure and function with remarkable precision. These technologies provide valuable insights into cerebral blood flow dynamics, microstructural integrity, and neurochemical changes, supporting data-driven decisions in injury prevention, return-to-play protocols, and performance optimization. As such, neurovisualization is becoming an essential component of athlete health surveillance and individualized medical care.

Monitoring Cerebral Perfusion During Intense Training

Cerebral perfusion plays a pivotal role in maintaining optimal brain function during high-intensity training, and monitoring its dynamics is essential for preventing exercise-induced neurovascular stress. As illustrated in Figure 4, high-intensity interval training (HIIT) leads to increased shear stress and cardiac output, enhancing cerebrovascular vasodilatory function and subsequently elevating cerebral blood flow (CBF). This improvement in CBF has been linked to neuroprotective benefits such as enhanced neurogenesis, synaptic plasticity, and protein clearance, facilitated by increased expression of neurotrophic factors like BDNF and IGF-1 (Kim et al., 2024; Altmann et al., 2024). Advanced neuroimaging techniques, including arterial spin labeling (ASL) MRI and transcranial Doppler ultrasound, allow for non-invasive, real-time assessment of cerebral hemodynamics during and after intense exercise (Borsos et al., 2024; Wu et al., 2024). These tools provide critical insight into the cerebrovascular adaptations driven by physical training and offer a mechanism for tracking the relationship between cardiorespiratory fitness, cognitive function, and brain health across time.

Figure 4. Potential Mechanisms Linking High-Intensity Exercise to Improved Cerebral Blood Flow and Brain Health (Taylor et al., 2022).



Detecting Silent Ischemia and Microbleeds

Silent ischemia and cerebral microbleeds represent subclinical yet clinically significant markers of cerebrovascular pathology that may predispose individuals, including athletes, to future neurological impairment. Silent ischemia, characterized by asymptomatic reductions in cerebral perfusion, often remains undetected without advanced neuroimaging but can indicate underlying vascular compromise or early-stage cerebrovascular disease (Yokoyama et al., 2022). Similarly, cerebral microbleeds small hemosiderin deposits resulting from vessel wall rupture are increasingly recognized as biomarkers of small vessel disease and heightened risk for intracerebral hemorrhage, especially in individuals undergoing high hemodynamic stress (Huang et al., 2024). Detection relies on high-resolution magnetic resonance imaging (MRI) sequences such as susceptibility-weighted imaging (SWI) and T2*-weighted gradient-recalled echo (GRE), which allow for precise visualization of microvascular abnormalities (Lin et al., 2023). Regular screening using these modalities in high-risk populations, including athletes engaged in intense physical activity, may aid in the early identification of covert cerebrovascular damage, enabling timely interventions to prevent long-term cognitive and neurological sequelae.

Brain Mapping for Return-to-Play Decisions

Brain mapping has emerged as a critical tool in guiding return-to-play (RTP) decisions following neurological events such as concussion, ischemia, or subclinical cerebrovascular impairments in athletes. Advanced neuroimaging techniques, including functional MRI (fMRI), diffusion tensor imaging (DTI), and quantitative electroencephalography (qEEG), offer detailed insights into neural connectivity, white matter integrity, and functional activation patterns that may be disrupted due to injury or insufficient recovery (Baradaran et al., 2023). These modalities allow clinicians to objectively assess neural network function and cognitive readiness, moving beyond symptom-based RTP protocols that may underestimate residual deficits. For instance, fMRI can identify alterations in task-related cortical activity during motor or cognitive tasks, while DTI can reveal microstructural damage to axonal pathways, which is especially relevant for evaluating subtle changes in executive and visuospatial functioning (Van Belle et al., 2022). Integrating brain mapping into RTP decision-making enhances the safety of athletic participation by ensuring that cerebral function has returned to baseline, thereby mitigating the risk of secondary injury.

Longitudinal Monitoring in High-Risk Athletes

Longitudinal monitoring in high-risk athletes provides critical insights into the cumulative effects of repetitive neurovascular stress and potential subclinical brain injury over time. Utilizing advanced imaging modalities such as diffusion tensor imaging (DTI), functional MRI (fMRI), and susceptibility-weighted imaging (SWI), clinicians can track microstructural and functional changes in the brain, enabling early detection of white matter degradation, altered connectivity, or emerging microbleeds (Benli et al., 2021). These techniques are particularly valuable in contact sports, where repeated subconcussive impacts may lead to chronic traumatic encephalopathy or other forms of progressive neurodegeneration despite the absence of overt symptoms (Simons et al., 2021). Longitudinal assessments also support personalized decision-making for training and return-to-play strategies by identifying trends in neurocognitive decline or recovery (McNamara et al., 2022). As such, long-term brain monitoring is increasingly recognized as a cornerstone of athlete health management and neuroprotection.

Case Reports and Clinical Findings

Case reports and clinical findings have significantly contributed to the understanding of cerebrovascular events in athletes, particularly in highlighting rare but critical occurrences such as exercise-induced ischemic strokes, transient ischemic attacks, and cerebral hemorrhages. Individual cases have documented how intense physical exertion, dehydration, or trauma can precipitate cerebrovascular compromise, sometimes in the absence of traditional risk factors (McClean et al., 2024). For example, reports of young, otherwise healthy athletes developing carotid artery dissection or posterior circulation strokes underscore the need for heightened clinical vigilance and neuroimaging in atypical presentations (Hopker et al., 2024). These clinical observations not only inform diagnostic protocols but also emphasize the importance of personalized risk assessment and early intervention strategies. Collectively, case-based evidence serves as a valuable complement to population-based studies, providing nuanced insights into the mechanisms, progression, and management of cerebrovascular events in the athletic population.

Integration with AI and Predictive Analytics

The integration of artificial intelligence (AI) and predictive analytics into neurovisualization represents a pivotal advancement in the proactive management of cerebrovascular health among athletes. By leveraging machine learning algorithms, deep learning architectures, and real-time physiological data, researchers and clinicians can extract meaningful patterns from complex neuroimaging datasets and predict stroke risk with unprecedented accuracy. This interdisciplinary convergence facilitates individualized monitoring, early detection of subclinical abnormalities, and informed decision-making regarding athletic performance and medical interventions. As AI technologies continue to evolve, their synergy with neurovisualization tools is poised to redefine the landscape of sports medicine and neurological prevention.

Role of Machine Learning in Neuroimaging Interpretation

Machine learning (ML) has emerged as a transformative tool in the interpretation of neuroimaging data, offering enhanced accuracy, efficiency, and scalability in identifying subtle cerebral abnormalities that may elude traditional analysis. By leveraging algorithms such as convolutional neural networks (CNNs), support vector machines (SVMs), and ensemble models, ML facilitates automated detection of ischemic lesions, microbleeds, and structural connectivity disruptions from modalities like MRI, fMRI, and DTI (Di Camillo et al., 2021). These methods have shown promise in differentiating pathological from normal brain patterns, predicting stroke outcomes, and quantifying neurodegenerative progression, thereby supporting early intervention in athletic populations exposed to neurovascular stress (Odusami et al., 2024). Furthermore, ML models can integrate multimodal datasets, combining imaging features with clinical, genetic, and performance metrics to produce individualized risk profiles and prognostic insights (Zhang et al., 2024). As neuroimaging datasets grow in complexity, machine learning is poised to become a cornerstone of precision neurodiagnostics in sports medicine.

Predictive Models for Stroke Risk Based on Imaging Biomarkers

Predictive modeling using imaging biomarkers has become an integral component of stroke risk stratification, particularly in athletic populations exposed to high physiological loads. Advances in artificial intelligence have enabled the development of robust algorithms that analyze features extracted from neuroimaging modalities such as white matter hyperintensities, cerebral microbleeds, and perfusion deficits to predict the likelihood of future cerebrovascular events (Jimenez-Mesa et al., 2024). Techniques such as logistic regression, random forests, and deep learning frameworks have demonstrated success in forecasting stroke risk by integrating structural and functional imaging data with demographic and clinical variables (Parvathy et al., 2025). These predictive models are increasingly applied in sports medicine to identify athletes with subclinical indicators of cerebrovascular vulnerability, supporting timely preventive measures and personalized training adjustments (Li & Zhong, 2024). By harnessing imaging biomarkers, AI-driven predictive analytics enhance precision in stroke prevention strategies and long-term neurological monitoring.

Real-Time Data from Wearables Linked to Neurovisualization

The integration of real-time physiological data from wearable devices with neurovisualization techniques represents a significant advancement in proactive brain health monitoring for athletes. Wearables capable of tracking heart rate variability, oxygen saturation, blood pressure, and physical exertion levels can provide continuous, non-invasive insights into systemic parameters that influence cerebral perfusion and vascular integrity (Lange et al., 2021). When linked with neuroimaging modalities such as functional MRI (fMRI) or near-infrared spectroscopy (NIRS), this data enables the dynamic assessment of brain function in response to physiological stressors, enhancing the temporal resolution and contextual relevance of neurovisualization (Sarada, 2022). Furthermore, machine learning algorithms can be applied to fuse these multimodal data streams, allowing for the identification of patterns predictive of cerebrovascular risk or cognitive fatigue in athletes (Karamesinis et al., 2021). This synergy between wearable technologies and neuroimaging lays the foundation for real-time, personalized monitoring systems that support injury prevention and optimize performance.

Challenges in Data Integration and Interpretation

Despite the promise of integrating artificial intelligence with neurovisualization and physiological monitoring, significant challenges remain in the harmonization and interpretation of heterogeneous data sources. One major limitation lies in the variability of neuroimaging protocols and wearable sensor outputs, which can introduce inconsistencies and bias into machine learning models, thereby affecting their generalizability and clinical utility (Ramesh et al., 2024). Moreover, the high dimensionality and multimodal nature of the data ranging from imaging biomarkers to real-time physiological signals necessitate complex preprocessing, feature extraction, and alignment techniques that often require domain-specific knowledge and computational resources (Shendyapina et al., 2022). Another challenge is the interpretability of AI models, particularly deep learning architectures, which may function as "black boxes" and hinder clinical adoption due to a lack of transparency and explainability (D Vinogradova et al., 2017). Addressing these issues is essential to ensure reliable, reproducible, and ethically sound implementation of AI-driven predictive analytics in neurovisualization for athletic health management.

Discussion

The findings of this review highlight the evolving role of neurovisualization in both clinical and experimental contexts, particularly concerning the early detection and monitoring of stroke risk among athletes. Clinically, neurovisualization techniques such as MRI, CTA, DTI, and PET have demonstrated significant utility in diagnosing cerebrovascular abnormalities, detecting silent ischemia, and guiding return-to-play decisions. These modalities allow healthcare providers to visualize structural and functional anomalies that may predispose athletes to cerebrovascular events, supporting individualized medical care and informed clinical decision-making. However, the transition from experimental research to routine clinical application remains challenged by issues of cost-effectiveness, accessibility, and the need for specialized expertise. High-resolution imaging modalities, while offering unparalleled diagnostic precision, entail significant financial and logistical burdens, often rendering them impractical for widespread preventive screening in sports settings, especially at the amateur or youth levels. The feasibility of incorporating such technologies into regular athlete health assessments depends largely on the availability of portable imaging solutions, streamlined protocols, and economic models that justify their preventive use.

The integration of artificial intelligence (AI) into neurovisualization analysis has shown promising results in enhancing diagnostic accuracy, pattern recognition, and predictive modeling. However, much of the literature referenced in this review discusses AI applications in general terms, often focusing on common machine learning models such as convolutional neural networks (CNNs) and support vector machines (SVMs), without detailing critical methodological aspects. In the reviewed studies, validation strategies varied considerably, with some employing cross-validation techniques to mitigate overfitting, while others utilized transfer learning approaches to adapt pre-trained models to limited neuroimaging datasets. Despite these methodological efforts, significant challenges persist regarding dataset heterogeneity, especially concerning scanner variability, image resolution, and preprocessing standards. Differences in imaging protocols across institutions may introduce biases and reduce the generalizability of AI models, underscoring the necessity for standardized data curation and harmonization efforts. Furthermore, explainability remains a major hurdle for the clinical deployment of AI systems. Methods such as Gradient-weighted Class Activation Mapping (Grad-CAM) and SHapley Additive exPlanations (SHAP) have been applied to visualize model decision pathways and improve interpretability, yet their use in neuroimaging applications specific to stroke risk in athletes remains limited. Bridging this gap between AI model performance and clinical trustworthiness is essential for advancing toward practical implementation.

The limitations of this review must also be acknowledged. Firstly, despite a comprehensive search strategy, the heterogeneity of the included studies in terms of sample sizes, imaging modalities, AI algorithms, and study designs complicates the direct comparison of findings and may introduce interpretative biases. Many of the reviewed works lack longitudinal data, making it difficult to assess the long-term predictive value of neurovisualization biomarkers in athletic populations. Furthermore, the limited inclusion of randomized controlled trials (RCTs) and prospective cohort studies restricts the strength of evidence regarding causal inferences. The variability in AI model training procedures, lack of standardized validation frameworks, and sparse reporting on explainability and clinical integration further constrain the extrapolation of experimental results to real-world practice. Finally, economic analyses addressing the cost-benefit ratio of implementing advanced neuroimaging and AI monitoring in sports contexts remain scarce, warranting further investigation. Future research should focus on large-scale, multicenter studies that incorporate standardized imaging protocols, rigorous AI validation methods, and comprehensive economic assessments to establish the clinical utility, feasibility, and cost-effectiveness of neurovisualization-assisted stroke risk monitoring in athletic populations.

Conclusions

In summary, the integration of neurovisualization techniques with artificial intelligence and predictive analytics represents a promising yet predominantly experimental approach to monitoring and managing stroke risk in athletes. Advanced imaging modalities, including functional MRI (fMRI), diffusion tensor imaging (DTI), susceptibility-weighted imaging (SWI), and computed tomography angiography (CTA), have shown significant potential in detecting subclinical cerebrovascular anomalies such as silent ischemia, microbleeds, and perfusion deficits. When enhanced by AI-driven algorithms and supported by physiological data from wearable devices, these technologies offer a comprehensive framework for individualized risk assessment, early detection, and informed return-to-play decisions. However, the current landscape is marked by a predominance of exploratory studies, often limited by small sample sizes, heterogeneity in imaging protocols, and a lack of validation in athletic populations. Most AI applications remain at a proof-of-concept stage, with limited large-scale, multicenter validations and no established standards tailored to the unique physiological characteristics of athletes. This underscores the urgent need for prospective cohort studies that systematically evaluate the longitudinal impact of neurovisualization-assisted monitoring in sports settings. Additionally, there is a critical requirement for the development of neuroimaging protocols specifically adapted to the dynamic cardiovascular and neurovascular responses associated with athletic performance. Addressing these gaps will require coordinated efforts among clinicians, researchers, and technologists to standardize methodologies, enhance AI model interpretability, and ensure the ethical application of neurovisualization tools in sports medicine. As the field advances, such collaborative approaches will be pivotal in transitioning from experimental models to practical, evidence-based interventions aimed at safeguarding athlete brain health and preventing cerebrovascular complications.

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References

Alekseeva, T. M., Topuzova, M. P., Kulikov, V. P., Kovzelev, P. D., Kosenko, M. G., & Tregub, P. P. (2024). Hypercapnic hypoxia as a rehabilitation method for patients after ischemic stroke. Neurological Research, 46(8), 695-705. https://doi.org/10.1080/01616412.2024.2343510

Altmann, S., Grauhan, N. F., Brockstedt, L., Kondova, M., Schmidtmann, I., Paul, R., ... & Othman, A. E. (2024). Ultrafast brain MRI with deep learning reconstruction for suspected acute ischemic stroke. Radiology, 310(2), e231938. https://doi.org/10.1148/radiol.231938

Ashikuzzaman, M., Huang, J., Bonwit, S., Etemadimanesh, A., Raghavan, P., & Bell, M. A. L. (2024, May). Deep learning-based displacement tracking for post-stroke myofascial shear strain quantification. In 2024 IEEE International Symposium on Biomedical Imaging (ISBI) (pp. 1-4). IEEE. https://doi.org/10.1109/ISBI56570.2024.10635186

Baradaran, H., Culleton, S., Stoddard, G., Alexander, M. D., Romero, J. R., Hadley, J. R., ... & McNally, J. S. (2023). Association between high-risk extracranial carotid plaque and covert brain infarctions and cerebral microbleeds. Neuroradiology, 65(2), 287-295. https://doi.org/10.1007/s00234-022-03062-0

Benli, M. D., Güven, B., Güven, H., & Conkbayır, I. (2021). Silent brain infarcts and white matter lesions in patients with asymptomatic carotid stenosis. Acta Neurologica Belgica, 121, 983-991. https://doi.org/10.1007/s13760-020-01517-w

Borsos, B., Allaart, C. G., & van Halteren, A. (2024). Predicting stroke outcome: a case for multimodal deep learning methods with tabular and CT perfusion data. Artificial Intelligence in Medicine, 147, 102719. https://doi.org/10.1016/j.artmed.2023.102719

Cherevko, A. A., Gologush, T. Y. S., & Ostapenko, V. V. (2021). Search for an Optimal Solution of the Problem of Arteriovenous Malformation Embolization by the Particle Swarm Method. Journal of Applied Mechanics and Technical Physics, 62, 530-541. https://doi.org/10.1134/S0021894421040027

Di Camillo, F., Grimaldi, D. A., Cattarinussi, G., Di Giorgio, A., Locatelli, C., Khuntia, A., ... & Sambataro, F. (2024). Magnetic resonance imaging–based machine learning classification of schizophrenia spectrum disorders: a meta-analysis. Psychiatry and clinical neurosciences, 78(12), 732-743.

Dobrynina, L. A., Shamtieva, K. V., Kremneva, E. I., Zabitova, M. R., Akhmetzyanov, B. M., Gnedovskaya, E. V., & Krotenkova, M. V. (2022). Daily blood pressure profile and blood–brain barrier permeability in patients with cerebral small vessel disease. Scientific Reports, 12(1), 7723. https://doi.org/10.1038/s41598-022-11172-1

Enyagina, I., Polyakov, A., & Kokovin, D. (2022, September). Medical IT service for the detection of neurocognitive pathologies based on the results of an MRI scan of the human brain. In 2022 Ivannikov Memorial Workshop (IVMEM) (pp. 15-19). IEEE. https://doi.org/10.1109/IVMEM57067.2022.9983966

Gologush, T. Y. S., Ostapenko, V. V., & Cherevko, A. A. (2021). Mathematical modeling of embolization of arteriovenous malformations with overflows on the basis of the two-phase filtering. Computational Mathematics and Mathematical Physics, 61, 1546-1558. https://doi.org/10.1134/S0965542521090104

Gutierrez, A., Amador, K., Winder, A., Wilms, M., Fiehler, J., & Forkert, N. D. (2024). Annotation-free prediction of treatment-specific tissue outcome from 4D CT perfusion imaging in acute ischemic stroke. Computerized Medical Imaging and Graphics, 114, 102376. https://doi.org/10.1016/j.compmedimag.2024.102376

Hao, S., Wang, Q., Tang, B., Wu, Z., Yang, T., & Tang, J. (2021). CDKL5 deficiency augments inhibitory input into the dentate gyrus that can be reversed by deep brain stimulation. Journal of Neuroscience, 41(43), 9031-9046. https://doi.org/10.1523/JNEUROSCI.1010-21.2021

Hopker, J. G., Griffin, J. E., Hinoveanu, L. C., Saugy, J., & Faiss, R. (2024). Competitive performance as a discriminator of doping status in elite athletes. Drug Testing and Analysis, 16(5), 473-481.

Huang, J., Biessels, G. J., de Leeuw, F. E., Ii, Y., Skoog, I., Mok, V., ... & Hilal, S. (2024). Cerebral microinfarcts revisited: detection, causes, and clinical relevance. International Journal of Stroke, 19(1), 7-15. https://doi.org/10.1177/17474930231187979

Ince, S., Kunduracioglu, I., Algarni, A., Bayram, B., & Pacal, I. (2025). Deep learning for cerebral vascular occlusion segmentation: a novel ConvNeXtV2 and GRN-integrated U-Net framework for diffusion-weighted imaging. Neuroscience, 574, 42-53. https://doi.org/10.1016/j.neuroscience.2025.04.010

Jimenez-Mesa, C., Ramirez, J., Yi, Z., Yan, C., Chan, R., Murray, G. K., ... & Suckling, J. (2024). Machine learning in small sample neuroimaging studies: Novel measures for schizophrenia analysis. Human Brain Mapping, 45(5), e26555.

Kalashnikova, L. A. (2022). Reversible Cerebral Vasoconstriction Syndrome and Its Complications. Human Physiology, 48(8), 984-993. https://doi.org/10.1134/S036211972208014X

Karamesinis, A., Sillitoe, R. V., & Kouzani, A. Z. (2021). Wearable peripheral electrical stimulation devices for the reduction of essential tremor: a review. IEEE Access, 9, 80066-80076. https://doi.org/10.1109/ACCESS.2021.3084819

Kim, D. W., Park, J. E., Kim, M. J., Byun, S. H., Jung, C. I., Jeong, H. M., ... & Baek, S. J. (2024). Automatic assessment of upper extremity function and mobile application for self-administered stroke rehabilitation. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 32, 652-661. https://doi.org/10.1109/TNSRE.2024.3358497

Kim, J. H., Chen, W., Chao, E. S., Chen, H., & Xue, M. (2021). Glutamatergic and GABAergic neurons mediate distinct neurodevelopmental phenotypes of STXBP1 encephalopathy. bioRxiv, 2021-07. https://doi.org/10.1101/2021.07.13.452234

Kim, J. H., Chen, W., Chao, E. S., Rivera, A., Kaku, H. N., Jiang, K., ... & Xue, M. (2024). GABAergic/glycinergic and glutamatergic neurons mediate distinct neurodevelopmental phenotypes of STXBP1 encephalopathy. Journal of Neuroscience, 44(14). https://doi.org/10.1523/JNEUROSCI.1806-23.2024

Koska, I. O., Selver, M. A., Gelal, F., Uluc, M. E., Çetinoğlu, Y. K., Yurttutan, N., ... & Dicle, O. (2024). Voxel level dense prediction of acute stroke territory in DWI using deep learning segmentation models and image enhancement strategies. Japanese journal of radiology, 42(9), 962-972. https://doi.org/10.1007/s11604-024-01582-8

Lange, A., Somov, A., Stepanov, A., & Burnaev, E. (2021). Building a behavioral profile and assessing the skill of video game players. IEEE Sensors Journal, 22(1), 481-488.

Lavrentev, S. N., Petrova, A. S., Serova, O. F., Vishnyakova, P., Kondratev, M. V., Gryzunova, A. S., ... & Silachev, D. N. (2024). Ultrasound Diagnosis and Near-Infrared Spectroscopy in the Study of Encephalopathy in Neonates Born under Asphyxia: Narrative Review. Children, 11(5), 591. https://doi.org/10.3390/children11050591

Li, Y., & Zhong, Z. (2024). Decoding the application of deep learning in neuroscience: a bibliometric analysis. Frontiers in Computational Neuroscience, 18, 1402689.

Lin, M. P., Demirer, M., Middlebrooks, E. H., Tawk, R. G., Erben, Y. M., Mateti, N. R., ... & Meschia, J. F. (2023). Greater burden of white matter lesions and silent infarcts ipsilateral to carotid stenosis. Journal of Stroke and Cerebrovascular Diseases, 32(9), 107287. https://doi.org/10.1016/j.jstrokecerebrovasdis.2023.107287

Lin, P. J., Li, W., Zhai, X., Sun, J., Pan, Y., Ji, L., & Li, C. (2024). AM-EEGNet: An advanced multi-input deep learning framework for classifying stroke patient EEG task states. Neurocomputing, 585, 127622. https://doi.org/10.1016/j.neucom.2024.127622

Liu, Y., Shah, P., Yu, Y., Horsey, J., Ouyang, J., Jiang, B., ... & Zaharchuk, G. (2024). A clinical and imaging fused deep learning model matches expert clinician prediction of 90-day stroke outcomes. American Journal of Neuroradiology, 45(4), 406-411. https://doi.org/10.3174/ajnr.A8140

Luo, J., Dai, P., He, Z., Huang, Z., Liao, S., & Liu, K. (2024). Deep learning models for ischemic stroke lesion segmentation in medical images: a survey. Computers in biology and medicine, 108509. https://doi.org/10.1016/j.compbiomed.2024.108509

Ma, M., Ganapathi, M., Zheng, Y., Tan, K. L., Kanca, O., Bove, K. E., ... & Bellen, H. J. (2024). Homozygous missense variants in YKT6 result in loss of function and are associated with developmental delay, with or without severe infantile liver disease and risk for hepatocellular carcinoma. Genetics in medicine, 26(7), 101125. https://doi.org/10.1016/j.gim.2024.101125

Martín Vicario, C., Rodríguez Salas, D., Maier, A., Hock, S., Kuramatsu, J., Kallmuenzer, B., ... & Muehlen, I. (2024). Uncertainty-aware deep learning for trustworthy prediction of long-term outcome after endovascular thrombectomy. Scientific Reports, 14(1), 5544. https://doi.org/10.1038/s41598-024-55761-8

Matsulevits, A., Coupé, P., Nguyen, H. D., Talozzi, L., Foulon, C., Nachev, P., ... & Thiebaut de Schotten, M. (2024). Deep learning disconnectomes to accelerate and improve long-term predictions for post-stroke symptoms. Brain Communications, 6(5), fcae338. https://doi.org/10.1093/braincomms/fcae338

McClean, Z. J., Pasanen, K., Lun, V., Charest, J., Herzog, W., Werthner, P., ... & Jordan, M. J. (2024). A Biopsychosocial Model for understanding training load, fatigue, and Musculoskeletal Sport Injury in University Athletes: a scoping review. The Journal of Strength & Conditioning Research, 38(6), 1177-1188.

McNamara, I. A., King, S. E., Corbin, W. R., & Fromme, K. (2022). A longitudinal examination of relations between competitive athletic participation, drinking norms, impulsivity, and sensation seeking and binge drinking throughout college. Psychology of Addictive Behaviors, 36(7), 837.

Mukhammadjonov, I. (2025). MODERN STANDARDS AND THEIR CONCEPTS IN TRANSIENT DISORDERS OF CEREBRAL CIRCULATION. Modern Science and Research, 4(3), 1649-1657. https://doi.org/10.5281/zenodo.15115964

Nunes, A. S., Yildiz Potter, İ., Mishra, R. K., Bonato, P., & Vaziri, A. (2024). A deep learning wearable-based solution for continuous at-home monitoring of upper limb goal-directed movements. Frontiers in Neurology, 14, 1295132. https://doi.org/10.3389/fneur.2023.1295132

Odusami, M., Maskeliūnas, R., Damaševičius, R., & Misra, S. (2024). Machine learning with multimodal neuroimaging data to classify stages of Alzheimer's disease: a systematic review and meta-analysis. Cognitive Neurodynamics, 18(3), 775-794.
Omarov, B., Omarov, B., Rakhymzhanov, A., Niyazov, A., Sultan, D., & Baikuvekov, M. (2024). Development of an artificial intelligence-enabled non-invasive digital stethoscope for monitoring the heart condition of athletes in real-time. *Retos, 60,* 1169–1180. https://doi.org/10.47197/retos.v60.108633
Omarov, N., Omarov, B., Azhibekova, Z., & Omarov, B. (2024). Applying an augmented reality game-based learning environment in physical education classes to enhance sports motivation. *Retos, 60*, 269–278. https://doi.org/10.47197/retos.v60.109170
Parvathy, R., Arunachalam, R., Damodaran, S., Al-Razgan, M., & Ali, Y. A. (2025). An intellectual autism spectrum disorder classification framework in healthcare industry using ViT-based adaptive deep learning model. Biomedical Signal Processing and Control, 106, 107737.
Peng, J., Ghosh, D., Zhang, F., Yang, L., Wu, J., Pang, J., ... & Jiang, Y. (2022). Advancement of epigenetics in stroke. Frontiers in Neuroscience, 16, 981726. https://doi.org/10.3389/fnins.2022.981726
Polamuri, S. R. (2024). Stroke detection in the brain using MRI and deep learning models. Multimedia Tools and Applications, 1-18. https://doi.org/10.1007/s11042-024-19318-1
Popugaev, K., Petrikov, S., & Abudeev, S. (2024). Central nervous system infection. In Neurological and Neurosurgical Emergencies (pp. 469-492). Academic Press. https://doi.org/10.1016/B978-0-443-19132-9.00020-0
Ramesh, S. H., Ouskine, A., Khorasani, E., Ebrahimipour, M., Finestone, H., Chan, A. D., & Rajabiyazdi, F. (2024, June). A Data Visualization Tool for Patients and Healthcare Providers to Communicate during Inpatient Stroke Rehabilitation. In Proceedings of the 50th Graphics Interface Conference (pp. 1-14).
Saleem, M. A., Javeed, A., Akarathanawat, W., Chutinet, A., Suwanwela, N. C., Asdornwised, W., ... & Kaewplung, P. (2024). Innovations in stroke identification: A machine learning-based diagnostic model using neuroimages. IEEE Access. https://doi.org/10.1109/ACCESS.2024.3369673
Sarada, M. (2022). Basics and descriptions of different biomedical signals. In AI-Enabled Smart Healthcare Using Biomedical Signals (pp. 1-25). IGI Global.
Sawan, A., Awad, M., Qasrawi, R., & Sowan, M. (2024). Hybrid deep learning and metaheuristic model based stroke diagnosis system using electroencephalogram (eeg). Biomedical Signal Processing and Control, 87, 105454. https://doi.org/10.1016/j.bspc.2023.105454
Shendyapina, M., Su, I. F., & Weekes, B. (2022). Cognitive assessment and rehabilitation tools for stroke and dementia: An online survey of Russian speaking clinicians. Applied Neuropsychology: Adult, 29(3), 295-314.
Simons, C., Martin, L. A., Balcombe, L., Dunn, P. K., & Clark, R. A. (2021). Mental health impact on at-risk high-level athletes during COVID-19 lockdown: A pre-, during and post-lockdown longitudinal cohort study of adjustment disorder. Journal of Science and Medicine in Sport, 24(4), 329-331.
Singh, S., Dawar, D., Mehmood, E., Pandian, J. D., Sahonta, R., Singla, S., ... & Mahadevappa, M. (2024). Determining diagnostic utility of EEG for assessing stroke severity using deep learning models. Biomedical Engineering Advances, 7, 100121. https://doi.org/10.1016/j.bea.2024.100121
Smerdov, A., Somov, A., Burnaev, E., Zhou, B., & Lukowicz, P. (2021). Detecting video game player burnout with the use of sensor data and machine learning. IEEE Internet of Things Journal, 8(22), 16680-16691. https://doi.org/10.1109/JIOT.2021.3074740
Steffen, K., & Engebretsen, L. (2015). Injury and illness surveillance among Olympic athletes: summary of the 2010 winter, and the 2008 and 2012 summer Olympic Games. Sports Injuries and Prevention, 39-50.
Taylor, J. L., Barnes, J. N., & Johnson, B. D. (2022). The utility of high intensity interval training to improve cognitive aging in heart disease patients. International journal of environmental research and public health, 19(24), 16926.
Van Belle, E., Debry, N., Vincent, F., Kuchcinski, G., Cordonnier, C., Rauch, A., ... & Susen, S. (2022). Cerebral microbleeds during transcatheter aortic valve replacement: a prospective magnetic resonance imaging cohort. Circulation, 146(5), 383-397. https://doi.org/10.1161/CIRCULATIONAHA.121.057145
van Voorst, H., Pitkänen, J., van Poppel, L., de Vries, L., Mojtahedi, M., Martou, L., ... & Caan, M. W. (2024). Deep learning-based white matter lesion volume on CT is associated with outcome after acute

ischemic stroke. European Radiology, 34(8), 5080-5093. https://doi.org/10.1007/s00330-024-10584-z
Vinogradova, O. L., Tomilovskaya, E. S., & Kozlovskaya, I. B. (2021). Gravity as a factor in evolutionary adaptation of animals to living on the earth. Human Physiology, 47(7), 716-7340. https://doi.org/10.1134/S0362119721070124
Wu, Z., Zhang, X., Li, F., Wang, S., & Li, J. (2024). A feature-enhanced network for stroke lesion segmentation from brain MRI images. Computers in Biology and Medicine, 174, 108326. https://doi.org/10.1016/j.compbiomed.2024.108326
Yang, T. H., Su, Y. Y., Tsai, C. L., Lin, K. H., Lin, W. Y., & Sung, S. F. (2024). Magnetic resonance imaging-based deep learning imaging biomarker for predicting functional outcomes after acute ischemic stroke. European journal of radiology, 174, 111405. https://doi.org/10.1016/j.ejrad.2024.111405
Yang, Y., & Guo, Y. (2024). Ischemic stroke outcome prediction with diversity features from whole brain tissue using deep learning network. Frontiers in Neurology, 15, 1394879. https://doi.org/10.3389/fneur.2024.1394879
Yokoyama, R., Kanzaki, Y., Watanabe, T., Yamamura, K., Komori, T., Takeda, Y., ... & Hoshiga, M. (2022). Prevalence and risk factors of silent cerebral microbleeds in patients with coronary artery disease. Journal of Stroke and Cerebrovascular Diseases, 31(1), 106211. https://doi.org/10.1016/j.jstrokecerebrovasdis.2021.1062
Yu, K., Fu, L., Chao, Y., Zeng, X., Zhang, Y., Chen, Y., ... & Xiao, Y. (2025). Deep learning enhanced near Infrared-II imaging and Image-Guided small interfering ribonucleic acid therapy of ischemic stroke. ACS nano, 19(10), 10323-10336. https://pubs.acs.org/doi/10.1021/acsnano.4c18035
Zhang, M., Treder, M., Marshall, D., & Li, Y. (2024). Explaining the predictions of kernel SVM models for neuroimaging data analysis. Expert Systems With Applications, 251, 123993.
Zhao, Z., Zhang, Y., Su, J., Yang, L., Pang, L., Gao, Y., & Wang, H. (2024). A comprehensive review for artificial intelligence on neuroimaging in rehabilitation of ischemic stroke. Frontiers in Neurology, 15, 1367854. https://doi.org/10.3389/fneur.2024.1367854
Zigmantovich, A. S., Oknina, L. B., Kopachka, M. M., Masherow, E. L., & Alexandrova, E. V. (2021). Functional wavelet connectivity in resting state reflects consciousness recovery in patients with severe traumatic brain injury. Human Physiology, 47(2), 128-136. https://doi.org/10.1134/S0362119721020146

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