THE IMPACT OF DIGITALIZATION ON THE NERVOUS SYSTEM: NEUROBIOLOGICAL MECHANISMS AND HEALTH IMPLICATIONS

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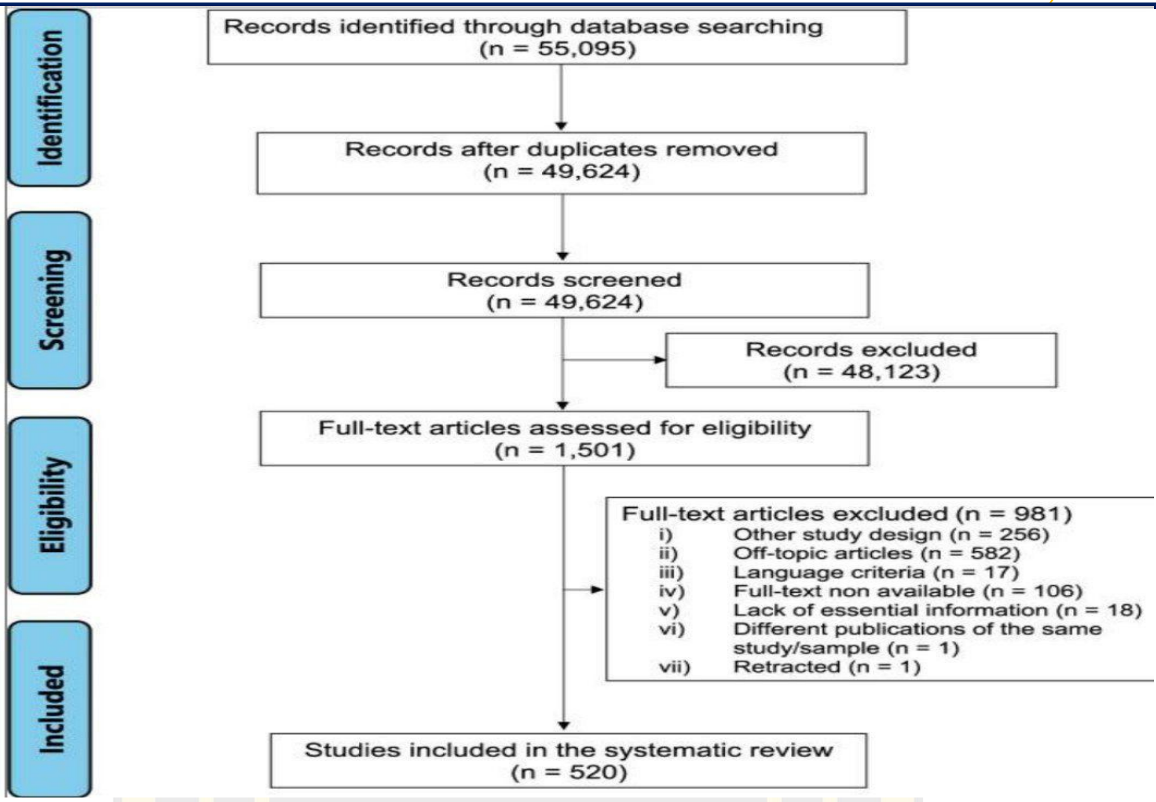
ABSTRACT

Digitalization has transformed modern life, increasing exposure to screens, information overload, and constant connectivity. This article explores how such digital environments influence the human nervous system. It reviews evidence showing chronic activation of stress pathways, changes in neuroplasticity, and immune-neuroendocrine dysregulation. Digital over-stimulation correlates with alterations in brain structure and function, impaired cognitive control, disrupted sleep, and increased anxiety. On the positive side, certain digital interventions—like brain-training games or cognitive apps—can support cognitive resilience. The article calls for public health strategies emphasizing "digital hygiene," balanced screen use, and further research into the long-term neurological effects of digital exposure.

Introduction: In recent decades, digital technologies have become ubiquitous. Smartphones, computers, social media, and constant internet access define daily life. While these technologies bring undeniable benefits, they also pose new challenges to the human nervous system. Persistent information exposure, multitasking, and "always-on" connectivity may act as chronic stressors, triggering neurobiological responses that affect our brain health and behavior. Scientific research suggests that digital over-stimulation affects multiple axes of the nervous system. For example, continuous screen use can chronically activate the hypothalamic-pituitary-adrenal (HPA) axis, increasing cortisol and altering immune responses. Neuroimaging studies point to changes in brain morphology associated with high screen time, especially in regions responsible for attention, memory, and executive control. Sleep disturbances, mood dysregulation, and anxiety are among the behavioral outcomes.At the same time, not all effects are negative. Digital tools designed for mental training, mobile cognitive exercises, and memory games have shown potential in improving neuroplasticity, especially in older adults. In the context of health, there is an emerging field of "digital neurotherapeutics," which aims to leverage technology to support brain function. This article aims to (1) summarize current findings on how digitalization impacts the nervous system, (2) discuss both adverse and beneficial effects, and (3) propose public health and clinical strategies for mitigating risks while harnessing the benefits of digital technology.

Analysis of the Reviewed Literature : New digital tools are constantly being introduced into clinical practice. This implementation is multifaceted and involves the use of digital technology in various stages of patient care, from electronic medical records to artificial intelligence for the diagnosis and evaluation of progression, treatment success, and even treatment. Most clinical diagnoses are made based on information obtained from the doctor's (first) personal contact with the patient, which almost always includes a physical examination. In line with this, a large survey of UK doctors found that 70% said the physical exam ination was 'almost always valuable' in the hospital setting. However, in contrast to practically all complementary exams, such as imaging and biofluid analyses, the digitalization of the physical examination is practically not implemented in any medical discipline. Fortunately, the digitalization of the physical examination is subject of great interest in the medical-scientific community and doctors understand that this digitalization process could not only lead to easier conduction of the physical examination but also to more and better data. The digitalization of the neurological examination (NE) may have particularly high potential due to the following reasons. Firstly, NE contains many elements that have to do with movements of the body or parts of the body, as well as with the language and vocalizations of the person being examined. The recording of these aspects is very advanced in the field of digital technology and associated algorithms (optical camera systems, eye trackers, wearable devices detecting mobility aspects, and microphones can be mentioned here), and in many versions even already available in consumer technology. Secondly, many diseases are chronically progressive or relapsing, and the clinical manifestations often change only subtly during the disease or a relapse. One strength of digital technology can be that even very subtle changes can be detected, but also that digital data can be stored and compared very accurately and objectively over time. This argument also applies, of course, to the evaluation of treatment response in the context of neurological diseases. Thirdly, the NE is complex and therefore difficult to learn and difficult to compare between different examiners. Standards for the various elements of the NE are largely lacking. It is interesting to note in this context that two-thirds of medical trainees reported they were never observed by a consultant when undertaking physical examination, and one-third reported that consultants have never demonstrated their use of the physical examination to them. Digital technology can substantially facilitate the development of skills in doctors in training, and they can substantially facilitate the comparison between examiners. As a neurological specialty, it could therefore make sense to advance the digitalization of the NE as efficiently and consensually as possible.



Results : The search terms led to 49,535 hits. After removing the duplicates, 49,414 articles were screened by reading the title and abstract. Finally, 520 articles met all the eligibility criteria, and their full texts were read (Fig. 1). The studies were carried out in 48 countries from 6 continents. Five countries accounted for more than 50% of the scientific publications: The United States of America (149, 28.6%), Germany (48, 9.2%), The United Kingdom (37, 7.1%), Italy (33, 6.3%), and Switzerland (28, 5.4%). Overall, 68,063 study participants were included. The median year of publication of the studies was 2018. Four hundred and twenty-four studies (81.5%) investigated the use of digital devices on patients with neurological disorders, while 96 (18.5%) studies involved only healthy persons. In 234 studies (45.0%), there was a comparison between patients and controls. In 48 studies (9.2%), researchers included patients with more than one neurological disorder. Parkinson's disease (140, 26.9%), Multiple Sclerosis (51, 9.8%), and Stroke (57, 11.0%) were the most investigated diseases. In 219 studies (42.1%), the authors intended to validate the digital method, and in 325 studies (62.5%) there was a comparison between the proposed new method and the current clinical gold standard assessment. Most of the technological devices were portable (442, 85.0%), and in 215 studies (41.3%), the devices were wearable. The cost of the devices usedwas described and discussed in 167 (32.1%) studies. Fiftysix (10.8%), 146 (28.1%), and 318 devices (61.1%) were classified as high, intermediate, and low complexity, respectively. One hundred and eighteen (22.7%), 143 (27.5%), and 259 (49.8%) devices generated immediate,

intermediate, and lengthy results, respectively. Most of the elements of the traditional NE have already been explored with digital devices. This includes (in descending order) gait (173 studies, 33.3%), motor system (149 studies, 28.6%), eyes (85 studies, 16.3%), cognitive functions (53 studies, 10.2%), sensory system (47 studies, 9.0%), balance (35 studies, 6.7%), other movements (24 studies, 4.6%), other cranial nerves (24 studies, 4.6%), coordination

(10 studies, 1.9%), and autonomic nervous system (9 studies, 1.7%). In 60 studies (11.5%), aspects from more than one element were investigated. Table presents more detailed information, including pathologies typically evaluated within the NE that have been addressed with these digital devices. In the cohorts studied here, digital technology was most often used to investigate aspects of gait, and the Inertial Measurement Unit (IMU) was the most frequently used instrument. In general, the complexity was variable, but the time taken to analyze and process the data was most often substantial. One hundred and fifty-seven (90.7%) and 119 (68.8%) of the devices were portable and wearable, respectively .The associated costs were reported in 54 (31.2%) studies. Many studies suggest that the digital examination of this element can provide important additional information on (early) detection, progression, and treatment response in various neurological diseases. For example, gait asymmetry and bilateral coordination during straight walking have been linked to prognosis and functional outcomes in multiple sclerosis (MS) . Several posturography parameters related to static balance have been associated with prodromal Huntington's disease (HD) or were used to objectify chronic subjective dizziness. In CACNA1A disorders, characterized by mutations in the calcium voltage-gated channel subunit alpha A, gait parameters such as gait speed, step width, and ankle range of motion have shown abnormalities, even when gait was clinically judged as unaffected by the investigator. Additionally, a significant number of variables derived from inertial movement units have been associated with disease progression in Parkinson's disease (PD), and specific gait parameters have been linked to functional improvement after acute stroke Although there are good examples demonstrating the usefulness of digital gait assessment, the literature also includes evidence that high

lights concerns regarding the widespread digitalization of this element of the NE. Hickey et al. showed that there may be a poor agreement between two different digital ways of assessing gait variability and asymmetry. A Dutch group found that the assessment of 5 meters of gait with a single body-fixed sensor had a high sensitivity but a low specificity in detecting Parkinsonian gait. In parallel, Hansen et al. demonstrated that temporal gait parameters showed only poor to moderate reliability in a cohort of neurogeriatric patients. In other cases, the results of gait

analyses were accurate and reliable, but they were not tested on patients with neurological diseases, which undermines their potential for incorporation into clinical practice.

Conclusion : Publications configured as reviews, letters to the editor, expert opinions, commentaries, conference proceedings, and editorials, and retracted papers were excluded. If the full text could not be found, or if an article had missing or uncertain key data, the corresponding author was contacted by e-mail up to two times, and the study was excluded if contact was unsuccessful. Articles were also excluded if they utilized digital tools for remote or telemedicine-based neurological examinations or if their primary aim was to promote neurological rehabilitation. In the case of publications referring to the same research sample and using the same technology to assess the same neurological feature, we only included the article with the largest sample

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