ARTIGO DE OPINIÃO | OPINION ARTICLE
Aging and Medical Rehabilitation: A Contribution to a Comprehensive Discussion

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Envelhecimento e Reabilitação Médica: Uma Contribuição para um Debate Abrangente

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Abstract

The rapid development of innovative technologies is transforming the landscape of elderly care and physical and rehabilitation medicine, addressing the unique challenges of aging. This document explores cutting-edge solutions, including smart house technologies (SHT), artificial intelligence (AI), virtual reality (VR), robotics, and advanced geriatric rehabilitation (GR) assessment strategies. These advancements enhance safety, autonomy, and quality of life for older adults and revolutionize therapeutic processes, making them more personalized and effective. By integrating these technologies into healthcare, we can create a future that empowers the elderly to age with dignity, autonomy, and improved well-being. GR is an increasingly relevant topic in medical science and society at large.

Keywords: *Aged; Artificial Intelligence; Physical and Rehabilitation Medicine; Robotics; Virtual Reality.*

Resumo

O envelhecimento populacional apresenta desafios complexos para os sistemas de saúde, particularmente na área da Medicina Física e de Reabilitação (MFR). Avanços tecnológicos recentes oferecem estratégias promissoras para enfrentar esses desafios, possibilitando uma mudança de paradigma na reabilitação geriátrica. Este artigo explora a integração de Tecnologias de Casa Inteligente (TCI), Inteligência Artificial (IA), Realidade Virtual (RV), robótica, sistemas baseados em sensores e avaliação geriátrica abrangente na prática e pesquisa em MFR. Estas tecnologias aumentam a autonomia, a segurança e o envolvimento, promovendo o cuidado individualizado e baseado em evidência. A TCI e a IA sustentam um monitoramento contínuo e intervenções personalizadas; a RV melhora a adesão e estimula a neuroplasticidade; a robótica e os sensores facilitam a mobilidade e as tarefas diárias; enquanto as avaliações geriátricas estruturadas garantem um planeamento terapêutico centrado no paciente. A convergência dessas ferramentas permite estratégias de reabilitação adaptativas, eficientes e éticas que não substituem, mas complementam o cuidado humano. À medida que a implementação clínica avança, é essencial avaliar criticamente seu impacto e manter uma abordagem multidisciplinar e focada no paciente. A incorporação efetiva dessas inovações pode promover um envelhecimento mais saudável e autónomo e redefinir os padrões de reabilitação para idosos.

Palavras-chave: Idoso; Inteligência Artificial; Medicina Física e de Reabilitação; Robótica; Realidade Virtual.

Smart House Technologies

The concept of a “smart house” refers to a home integrated with advanced technologies designed to simplify daily activities, particularly for individuals facing limitations in

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activity and participation. These technologies, often classified as assistive devices, play a crucial role in enhancing independence, functionality, and overall well-being. Assistive technology is frequently the first step in ensuring that people with disabilities are both beneficiaries of, and contributors to, rehabilitation programs.

Smart house technologies (SHT) are especially beneficial for elderly individuals, as they promote autonomy, safety, and a higher quality of life. These systems encompass a broad range of features, including environmental controls (such as regulating temperature and humidity), the management of doors, windows, lighting, and appliances, and the integration of therapeutic and assistive devices. Beyond this, emerging technologies like virtual and augmented reality, social networks, and smart vehicles further expand the advantages of smart homes.

One of the primary functions of smart house technology is ensuring safety. Sensors, cameras, and motion detectors monitor falls or periods of inactivity, and can automatically send alerts to caregivers. Emergency response systems ensure that older adults or individuals with health conditions receive prompt assistance in case of accidents or medical events.

Health monitoring is another key aspect. Wearable devices and in-home sensors can track vital signs like blood pressure and heart rate, issuing alerts when necessary. Telemedicine platforms are also integrated, allowing for virtual consultations and increasing access to healthcare services.

Automation of daily tasks is central to the smart house experience. Voice-controlled assistants manage lighting, appliances, and provide medication reminders, while smart appliances enable remote control and scheduling, offering both convenience and safety.

Additionally, SHT enhances social connections. Communication platforms, entertainment systems, and cognitive stimulation tools such as video calls, streaming services, and audiobooks help foster emotional well-being and reduce isolation. In rehabilitation, patient care should focus on identifying individual needs to tailor the appropriate prescription of these smart house technologies.

Artificial Intelligence for Enhancing Autonomy

According to Regulation 2024/1689 of the European Parliament and the Council, an artificial intelligence (AI) system is one that, based on the data it receives, can infer how to produce outputs such as predictions, content, recommendations, or decisions, beyond simple data processing, enabling learning, reasoning, or modeling with various levels of autonomy.

In the context of aging and rehabilitation, particularly in Physical and Rehabilitation Medicine (PRM), AI has become increasingly relevant due to the dramatic expansion of data availability. This growth is driven by advances in digital health, electronic medical records, and technologies such as sensors and imaging devices, which have facilitated more comprehensive data collection and storage. As an optimized data analysis tool, AI has emerged as a critical component in scientific research, particularly in developing strategies to promote autonomy and improve quality of life among older adults.

However, the integration of AI into clinical and research practices requires a precise definition of its roles. For rehabilitation physicians and researchers, the priority is to actively shape AI's application to address specific clinical needs and scientific inquiries. This begins with clearly defining the desired outcomes and formulating well-constructed research questions to guide AI-driven investigations. Subsequently, it is essential to identify data that are both relevant and representative of the clinical context. Ensuring data quality and accuracy during collection is crucial, as flawed inputs can propagate errors throughout the analysis, a concern embodied in the "garbage in, garbage out" principle. At advanced stages, once AI-generated results are obtained, critical evaluation is necessary to refine the system, seeking to achieve maximum data resolution with minimal data input, while leveraging clinical insight to ensure meaningful outcomes.

Ultimately, despite AI's powerful data analysis capabilities, clinical reasoning and critical thinking remain indispensable in generating clinically relevant insights and enhancing independence in older populations.

Virtual Reality and Gamification in Rehabilitation for Aging Populations

The global phenomenon of population aging presents significant challenges for public health, particularly in addressing the gradual decline in physical and cognitive capacities among older adults. Traditional rehabilitation approaches often face limitations in engaging elderly patients. In this context, VR and gamification emerge as innovative tools that can enhance rehabilitation outcomes by integrating science and technology into treatment paradigms.

VR offers a unique therapeutic advantage by simulating interactive, immersive environments tailored to the specific needs of patients. The immersive nature of VR enhances motivation and adherence to therapy, promoting more

intensive and consistent practice. VR allows for real-time feedback, enabling instant adjustments to exercises and personalized interventions. This aspect is particularly beneficial for older adults, as it facilitates safer practice environments where errors, such as falls, do not have physical consequences, reducing fear and improving confidence.

Gamification further augments the rehabilitation experience by incorporating elements of reward, competition, and progression, which are designed to stimulate patient engagement. By turning rehabilitation exercises into rewarding experiences, gamification leverages the brain's reward system to enhance pleasure and motivation, ultimately improving treatment adherence.

Scientific evidence suggests that VR-based rehabilitation promotes neuroplasticity by stimulating synaptic connections, leading to improvements in motor and cognitive functions. Studies have demonstrated that VR environments can improve balance, reduce the risk of falls, and enhance overall physical performance in older adults. Therefore, VR and gamification represent promising alternatives to traditional rehabilitation methods, offering a more engaging, motivating, and effective approach to aging populations.

Robotics, Sensor Technology and Autonomy

Advancements in electronics, computer systems, wireless communications and AI, have led to the generalized use of sensors and "smart" devices, where communication and digitalization are omnipresent. At the same time, life expectancy is growing and family structure has changed leading to a great number of still independent older people living alone, at least part of the day. This is leading to the emergence of electronic systems and devices for assistive aging and activities, like maintenance physical therapy, serious games, automatic health monitoring, social interaction or emergency communication, that promote autonomy and quality of life of elder people.

Recent advances in electronics and sensors include the development of wearable bioelectronic patches and e-textiles. These technologies allow wireless monitoring of vital signs including EEG, heart rate, respiration, motion (acceleration and inclination) oxygen saturation and body temperature in a compact, flexible casing.

A new recent trend is the development of social robots. These are usually humanoid wheeled robots for interaction with people using AI techniques like large language models (LLM), able to keep a "normal" conversation with humans.

Another set of equipment being developed consist of traditional devices used by elder people, like walkers and wheel chairs, that are enhanced with sensors and electronics as in an Autonomous Mobile Robot.

Some of referred systems are already available at a commercial level and it is expected that some others will appear soon in the market, improving the quality of life and allowing elder, alone people to keep living in their homes longer with an acceptable quality of life and suitable follow-up by family and other care providers.

Geriatric Rehabilitation Assessment

Population aging is globally one of the most significant social transformations of the century, with cross-sectoral implications. Despite being individualized and with a multifactorial predisposition, the aging process leads to progressive multiple organ deterioration, less ability to adapt and loss of autonomy, thus increasing personal, social and economic burden. It is, therefore, essential to early invest in strategies that promote the quality of aging, maximizing health, well-being and the ability to live autonomously in interaction with the environment. Geriatric rehabilitation (GR) is a multidimensional approach that aims to optimize functional performance, preserve functional reserve, promote activity and maintain social participation in older people with disability. Differentiated assessment begins with a comprehensive evaluation of the multiple factors that influence rehabilitation potential, including the characterization of the functional loss (time of onset, precipitating factors, compensatory strategies) and the identification of impairments, health conditions and contextual factors. Based on the expectations of functional and/or quality of life improvements, GR assessment then includes patient-centered programs that should be clinical and functionally tailored to the particularities of the elderly population, structured, goal-oriented, temporally defined (early-started, with a temporal allocation and regular evaluations of progress) and, if feasible, carried out in an ambulatory setting (preferably at patient's environment) and supported by a coordinated multidisciplinary team that includes the patient and the caregivers. Consensual measurement methods should be used not only for evaluation purposes but also to target individual rehabilitation needs and patient outcomes. Several e-health devices and technologies designed to evaluate, monitor, self-manage, increase accessibility and treat, have shown growing interest, applicability and receptivity in GR. However, there are still inherent challenges of its implementation and the need for better characterization of its clinical impact, as they should be adopted when superior to non-electronic solutions.

Discussion and Conclusion

The aging of the population is an irreversible phenomenon with global expression, exposing new challenges to research and practice of medicine, rehabilitation, and healthcare. The use of emerging technologies such as AI, SHT, VR and robotics represents a significant revolution in the way we approach elderly care and rehabilitation. These modern interventions can offer solutions to enhance functionality and to improve quality of life, but can also indicate a significant transformation in therapeutic processes, making them more effective, personalized, and accessible.

The comprehensive use of these technologies prospects the construction of highly adaptable assistive environment that responds to the individual needs, monitoring outcomes in real-time and providing specific and customized interventions, oriented to a more adapted training and performance. AI, for example, acknowledges the analysis and interpretation of large volumes of data, developing more precise strategies for diagnosis and therapeutic interventions. SHT, equipped with interconnected technological devices, promotes a safe and comfortable environment while offering continuous support in performing activities of daily living. VR, gaming and robotics revealed great potential in physical and cognitive rehabilitation, providing more interactive and motivating exercises, as well as enabling cognitive, mobility and functional recovery.

However, despite the great potential of these technologies, their use in PRM must be attended by ethical reflection, evidence-based practice and a patient-centered comprehensive approach. The implementation of these strategies should not replace human intervention but rather should be understood as a complement, enhancing the possibilities for care and rehabilitation through more traditional programs. The individualization of interventions, and respecting the individual's conditions, objectives and preferences, will always be the key to the success of any technological approach.

The merging of technologies in medical rehabilitation offers a promising development field of action leading to the future of quality of life of the elderly. The effective integration of these innovations can guide us in a new era of medical care and rehabilitation, transforming aging into a healthier, more active, and fulfilling experience. This paper provides a summary of the presentations given at the Portuguese Society of Physical and Rehabilitation Medicine Congress, held in September 2024.

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