bioengineering

MDPI

Editorial

Technologies for Monitoring and Rehabilitation of Motor Disabilities

Claudia Ferraris [1,*] and Veronica Cimolin [2,3]

[1] Institute of Electronics, Computer and Telecommunication Engineering (IEIIT), National Research Council of Italy (CNR), 10129 Turin, Italy
[2] Department of Electronics, Information and Bioengineering (DEIB), Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, Italy; veronica.cimolin@polimi.it
[3] IRCCS Istituto Auxologico Italiano, San Giuseppe Hospital, 28824 Verbania, Italy
* Correspondence: claudia.ferraris@cnr.it

1. Introduction

Motor disabilities resulting from stroke, neurodegenerative, neuromuscular, and neurodevelopmental conditions, or injuries can substantially limit independence and participation in daily life. According to the analysis reported in [1], approximately 2.41 billion people worldwide already have a health condition that could benefit from rehabilitation in 2019. This number is expected to increase further with population aging, placing additional pressure on healthcare services and their accessibility. Bioengineering technologies and digital solutions [2] can help address these challenges by enabling objective, repeatable, and personalized assessments of motor function and supporting more tailored rehabilitation interventions. Advances in wearable sensors [3], brain–computer interfaces [4], robotic systems [5], and virtual environments [6] could extend functional monitoring beyond clinical settings and support more intensive and tailored rehabilitation treatments.

The Special Issue "Technologies for Monitoring and Rehabilitation of Motor Disabilities" aimed to bring together research on innovative technologies for motor assessment, monitoring, rehabilitation, and assistance. Five articles were published, including one review and four original research articles, covering hybrid brain–computer interfaces, neurophysiological assessment of motor recovery, musculoskeletal modeling, instrumented gait analysis, and assistive orthoses. This editorial summarizes their main contributions, discusses common challenges, and outlines potential directions for future research.

2. Overview of Published Contributions

2.1. Brain Signals and Motor Recovery

Chen et al. [7] reviewed brain–computer interfaces (BCIs) combining functional near-infrared spectroscopy (fNIRS) and electroencephalography (EEG) for motor rehabilitation. Drawing on 23 key studies, the authors highlighted how EEG's high temporal resolution and spatial information provided by fNIRS can improve classification performance. They analyzed hardware, signal processing, and machine and deep learning approaches, identifying wearability, signal synchronization, and the lack of standardized experimental protocols as major challenges. Building on this overview, the authors concluded that combining hybrid BCIs with other technologies, including functional

Received: 20 November 2026
Accepted: 22 November 2026
Published: 24 November 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

electrical stimulation, virtual reality, or brain stimulation, points to the future development of closed-loop rehabilitation systems, possibly broadening their use beyond clinical settings.

Liu et al. [8] conducted a randomized, double-blind, sham-controlled trial with 36 people with chronic stroke, comparing transcranial direct current stimulation (tDCS) over the premotor cortex (PMC) or primary motor cortex (M1) with sham stimulation, each followed by mirror therapy. While no significant between-group differences in improvements in activities of daily living (ADLs) were observed, EEG alpha power showed distinct associations with ADL gains: over the temporal regions in the PMC group and over the central–frontal regions in the M1 group. These findings support potentially distinct neurophysiological mechanisms and highlight the value of EEG-derived indices in characterizing rehabilitation responses alongside conventional clinical outcomes, with potential relevance for personalized motor rehabilitation.

2.2. Gait Biomechanics and Orthotic Assessment

Brunner and Frigo [9] used a multisegment musculoskeletal model to investigate why some individuals with cerebral palsy (CP) develop crouch gait despite preserved plantar flexor strength. The simulations showed that plantar flexor action contributes to knee extension only when the ground reaction force passes anterior to the knee joint center, a condition that is lost beyond approximately 25° of knee flexion in an upright posture or 40° with forward trunk inclination. These analyses provide a biomechanical explanation for the limited effectiveness of plantar flexor control in certain gait configurations, with potential consequences for understanding orthotic treatment results and planning rehabilitation interventions.

Camuncoli et al. [10] integrated an instrumented treadmill, motion capture, and virtual reality to compare a new-generation sports-specific ankle–foot orthosis (AFO) with conventional AFOs in 18 children with hemiplegic cerebral palsy during level, uphill, and downhill walking. The new orthosis produced significant changes in ankle and foot kinematics, as well as trunk and hip rotations, particularly during downhill walking. Walking slope also substantially affected gait patterns, independently of the orthosis type. The study highlights the importance of assessing orthotic devices under different simulated walking conditions to support more individualized interventions.

2.3. Assistive Devices and the User's Perspective

Rao et al. [11] evaluated a chair-mounted passive trunk orthosis designed for individuals with dystrophinopathy, in whom progressive muscle weakness and fatigue can substantially affect daily activities. The study assessed the surface electromyography (EMG) and perceived exertion in 40 healthy participants performing seated reaching tasks, while 15 patients with dystrophinopathy evaluated the device's usability using the System Usability Scale. The orthosis did not produce significant changes in EMG median frequency, while patients reported acceptable usability. By combining physiological, perceptual, and user-centered measures, the study highlights the importance of multidimensional assessment in the development and evaluation of assistive technologies.

3. Knowledge Gaps and Future Directions

Taken together, these contributions emphasize three key aspects that connect technological development and clinical applications. First, they advance understanding of the mechanisms underlying motor impairment and rehabilitation responses, through biomechanical modeling [9] and neurophysiological measures [8]. Second, they point out the importance of functional relevance of technologies, by evaluating assistive devices

under different simulated conditions [10] and considering daily-life outcomes and user experience [8,11]. Third, they highlight the value of integrating complementary information, whether from different brain signals [7] or from physiological, perceptual, and user-centered measures [11].

Nevertheless, several challenges remain, particularly around clinical validation, methodological standardization, and translating technological solutions into everyday monitoring and rehabilitation practice. Some topics within the initially defined scope of the Special Issue, including wearable sensors for long-term monitoring, markerless video analysis, exergames, and artificial intelligence for clinical decision support, were underrepresented. Combining these technologies into more comprehensive systems could help address the three aspects highlighted above and open new opportunities for monitoring and rehabilitation. Therefore, future research should focus on developing multimodal, adaptive, closed-loop monitoring and rehabilitation systems; advancing personalized assessment through subject-specific models; validating digital biomarkers; and extending monitoring and rehabilitation beyond controlled, supervised environments. Larger multicenter studies, uniform and consistent protocols, and human-centered design approaches will also be essential to establish the clinical relevance, usability, and long-term applicability of these technologies.

4. Conclusions

The five contributions to this Special Issue illustrate the potential of bioengineering technologies to advance understanding, assessment, and rehabilitation of motor disabilities, from the analysis of brain activity and movement biomechanics to the evaluation of assistive devices. Together, they highlight the importance of integrating technological innovation with rigorous methods and clinically meaningful outcomes to support the development of more effective, personalized monitoring and rehabilitation strategies.

We sincerely thank all the authors for their valuable contributions, the reviewers for their careful evaluations, and the *Bioengineering* Editorial staff for their support.

Author Contributions: Conceptualization, C.F. and V.C.; writing—original draft preparation, C.F. and V.C.; writing—review and editing, C.F. and V.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Cieza, A.; Causey, K.; Kamenov, K.; Hanson, S.W.; Chatterji, S.; Vos, T. Global Estimates of the Need for Rehabilitation Based on the Global Burden of Disease Study 2019: A Systematic Analysis for the Global Burden of Disease Study 2019. *Lancet* **2020**, *396*, 2006–2017. https://doi.org/10.1016/S0140-6736(20)32340-0.
2. Arntz, A.; Weber, F.; Handgraaf, M.; Lällä, K.; Korniloff, K.; Murtonen, K.-P.; Chichaeva, J.; Kidritsch, A.; Heller, M.; Sakellari, E.; et al. Technologies in Home-Based Digital Rehabilitation: Scoping Review. *JMIR Rehabil. Assist Technol.* **2023**, *10*, e43615. https://doi.org/10.2196/43615.
3. Porciuncula, F.; Roto, A.V.; Kumar, D.; Davis, I.; Roy, S.; Walsh, C.J.; Awad, L.N. Wearable Movement Sensors for Rehabilitation: A Focused Review of Technological and Clinical Advances. *PM R* **2018**, *10*, S220–S232. https://doi.org/10.1016/j.pmrj.2018.06.013.
4. Meng, J.; Wei, Y.; Mai, X.; Li, S.; Wang, X.; Luo, R.; Ji, M.; Zhu, X. Paradigms and Methods of Noninvasive Brain-Computer Interfaces in Motor or Communication Assistance and Rehabilitation: A Systematic Review. *Med. Biol. Eng. Comput.* **2025**, *63*, 2209–2233. https://doi.org/10.1007/s11517-025-03340-y.

5. Banyai, A.D.; Brișan, C. Robotics in Physical Rehabilitation: Systematic Review. *Healthcare* **2024**, *12*, 1720. https://doi.org/10.3390/healthcare12171720.
6. Laver, K.E.; Lange, B.; George, S.; Deutsch, J.E.; Saposnik, G.; Chapman, M.; Crotty, M. Virtual Reality for Stroke Rehabilitation. *Cochrane Database Syst. Rev.* **2025**, *6*, CD008349. https://doi.org/10.1002/14651858.CD008349.pub5.
7. Chen, J.; Xia, Y.; Zhou, X.; Vidal Rosas, E.; Thomas, A.; Loureiro, R.; Cooper, R.J.; Carlson, T.; Zhao, H. fNIRS-EEG BCIs for Motor Rehabilitation: A Review. *Bioengineering* **2023**, *10*, 1393. https://doi.org/10.3390/bioengineering10121393.
8. Liu, C.-L.; Tu, Y.-W.; Li, M.-W.; Chang, K.-C.; Chang, C.-H.; Chen, C.-K.; Wu, C.-Y. Electroencephalogram Alpha Oscillations in Stroke Recovery: Insights into Neural Mechanisms from Combined Transcranial Direct Current Stimulation and Mirror Therapy in Relation to Activities of Daily Life. *Bioengineering* **2024**, *11*, 717. https://doi.org/10.3390/bioengineering11070717.
9. Brunner, R.; Frigo, C.A. Control of Tibial Advancement by the Plantar Flexors during the Stance Phase of Gait Depends on Knee Flexion with Respect to the Ground Reaction Force. *Bioengineering* **2024**, *11*, 41. https://doi.org/10.3390/bioengineering11010041.
10. Camuncoli, F.; Malerba, G.; Biffi, E.; Diella, E.; Di Stanislao, E.; Rosellini, G.; Panzeri, D.; Piccinini, L.; Galli, M. The Effect of a New Generation of Ankle Foot Orthoses on Sloped Walking in Children with Hemiplegia Using the Gait Real Time Analysis Interactive Lab (GRAIL). *Bioengineering* **2024**, *11*, 280. https://doi.org/10.3390/bioengineering11030280.
11. Rao, A.Z.; Danish Mujib, M.; Abul Hasan, M.; Alokaily, A.O.; Tahira, T.; Qazi, S.A. User Perspectives and Psychophysiological Manifestations of Fatigue with Trunk Orthosis for Dystrophinopathy Patients. *Bioengineering* **2024**, *11*, 780. https://doi.org/10.3390/bioengineering11080780.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.