Biomechatronics: people with disabilities or technology with limitations?

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Abstract. This research has an objective to broach the impact of biomechatronics on health, looking for encourage the research, design, and development in the different levels of university education through a literature review. The search was carried out in conferences, books, interviews, original and review articles between 2000 to 2020. The descriptors used are biomechatronics, disability, technology, artificial intelligence, on the ScienceDirect and Scielo databases. The search resulted in 174; after the exclusion of duplicates and selection through title and systematic review, 28 articles were included in the research. The discoveries evince a great interest in the development of biomechatronics in order to help the human being to overcome difficulties caused by health, accidents, or genetics, integrating technologies like artificial intelligence, nanotechnology, tissue engineering, 3D printing, among others, which is of academic interest and of reflection due to the technological, scientific, and ethical implications

Key words: biomechatronics, disability, artificial intelligence, nanotechnology, tissue engineering.

1. Introduction

Currently, there are more than 1 billion people with some disability and their lives depend on another (World Bank, 2021); however, biotechnology has a principal role in the emancipation of disabled people by developing technology capable of helping people with problems to interact with their environment and overcome the crisis. Without a doubt, technological innovations contribute to change and optimize their lives. Therefore, some universities, companies, and specialized laboratories took on the task of developing technology that fuse human body with mind, completely changing the concept of human capacity, like the Massachusetts Institute of Technology in the United State (Evers, 2018), implementing some sciences like the biomechatronics and looking for integrate electronic and mechanical elements and part of biological organisms to assist the human body with deficiencies caused by diseases, accidents, or birth defects (Harrasser, 2018).

It is necessary to highlight that this field has not reached all its potential due to the high costs inherent to research, design, tests, and prototypes. There are few entities willing to invest in that despite the great benefit it means for humanity by return mobility or lost capacity of a lost limb at some point. The contributions range from recovering a leg to the sense of hearing; recent contributions have been focused on shock absorbers or sockets to minimize the pain and offer a greater comfort in implants or prosthesis.

Regarding the aforementioned, this article has as objective to carry out a systematic descriptive research about the benefits and impact of biomechatronics when incorporating innovative systems into individuals, helping to minimize or eliminate the physical disability and allowing to amplify the view of professional in different fields to promote, assume, and achieve a social labor, as well as promote the research, design, or development of this science in the different university levels. The selected sources of academic exploration were the ScienceDirect and Scielo databases during the years 2000-2020, originating a matrix analysis with relevant information about the subject matter.

2. Methodology

The research method used in the development of the article was the systematic literature review, identifying, analyzing, and monitoring the subject matter, applying a type of descriptive review, beginning from updated data in order to amplify the knowledge. Likewise, the search of topic was carried out in secondary sources of information to define derivations and possible research gaps; moreover, it was developed following the declaration Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) in the following stages (Hernández and Camargo, 2017):

In the first stage, in order to include academic literature related, ScienceDirect and Scielo databases were chosen, establishing the period 2000-2020 as the search range; in the exploration of conferences, books, interviews, original and review articles, the inclusion criteria correspond to the descriptors: biomechatronics, disability, technology, artificial intelligence, in English for ScienceDirect and in Spanish for the second choice. Additionally, logical connectors such as 'and' and/or 'or' (see Figure 1).

Figures

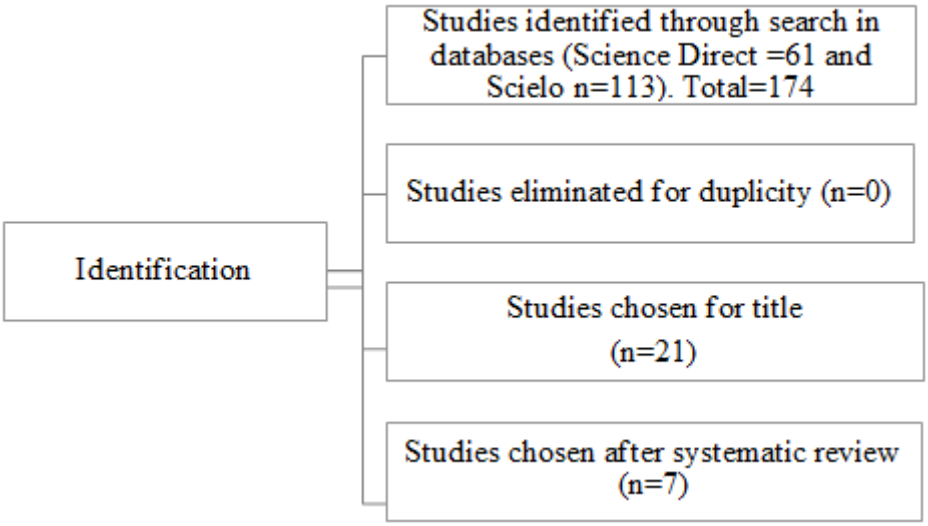

Figure 1. PRISMA Diagram
Source: Own elaboration.

Exclusion criteria are defined with the publication date, only the established range is considered, consolidating 61 derivations for ScienceDirect and 113 concurrences for Scielo. Table 1 shows the coincidences per year and database.

Tables

Table 1 Comparative matrix per year

Year	Scielo	ScienceDirect
2020	18	7
2019	10	13
2018	4	15
2017	2	5
2016	1	1
2015	2	4
2014	6	3
2013	7	2
2012	17	2
2011	15	0
2010	8	0

2009	11	1
2008	4	2
2007	3	0
2006	1	4
2005	1	1
2004	0	1
2003	2	0
2001	1	0
Total	113	61

The second stage corresponds to create a matrix analysis structured to consolidate the data according to author(s), year of publication, title, general objective, and findings. In the third stage, the resulting studies were screened considering the search criterion. Then, they were analyzed, prioritizing 28 articles that explicitly refer the subject matter (See Table 2).

Table 2 Matrix

Author(s)/year	Title	General objectives	Findings
Science Direct			
Lechler, K., Frossard, B., Whelan, L., Langlois, D., Müller, R., Kristjansson, K. (2018)	Motorized Biomechatronic Upper and Lower Limb Prostheses—Clinically Relevant Outcomes	Provide a review of state of biomechatronic developments in prosthesis of upper and lower limbs in the context of different challenges of amputations and clinically relevant results.	People with major limb amputations are severely impaired when it comes to activity, body structure and function, as well as participation. It has been demonstrated that the use of prosthesis has a positive impact on mobility and depression, thereby affecting the life quality. Biomechatronic prosthesis are at the forefront of the prosthetic development. Actively powered designs are now regularly used for upper limb prosthesis, whereas the clinic use of actively powered prosthesis for lower limbs has been limited to a very reduced number of applications.
Ulloa, J. (2018)	Capítulo 1 - Introducción a la biomecatrónica / ingeniería biomédica	Study the most frequent human neurological diseases, identifying its necessities to propose biomechatronic devices that can be applied to create solutions to human movement disorders, as confirmation of diagnosis, rehabilitation.	Explanation of the necessity to develop solutions where the mechanic and electronic interact with the human skeleton and nervous system to detect organs or limbs damaged by an injury, disease, or birth defects. Presentation of the advantage of having methodologies to develop biomechatronic solutions based on data acquisition, data analysis, and steps to obtain mathematical models to represent the behavior of the health problem under study, based on kinematics/ kinetics of the human body to develop biomechatronic devices.
Novak, D. (2019)	Chapter Five - Biomechatronic	Analyze the different kinds of signals in brain-	Present several possible biomechatronic applications:

	Applications of Brain-Computer Interfaces.	computer interfaces (BCI) (electroencephalography, electrocorticography, intracortical electrodes, and functional near-infrared spectroscopy), as well as different paradigms of motor, mental and potential images visually evoked in stable state.	control of powered wheelchairs, mobile robots, artificial limbs, communication devices, BCI-triggered rehabilitation devices, adaptive automation, task difficulty adaptation, and detection of errors.
Ruíz, A., López, A., Ferreira, A. (2019)	Chapter Eight - Upper and Lower Extremity Exoskeletons.	Analyze the literature. There are multiple lines of work aimed at developing robotic devices focused on the human being.	The rehabilitation field is a key application domain for the development of exoskeletons, to help disabled people with difficulties in moving and allow people with paralysis of the lower part of the body (paraplegia) to walk. Their task is the compensation for the lost functions and the physical and social rehabilitation of patients. Currently, the exoskeletons systems progress with a high integration using other emerging technologies such as the virtual reality, haptics, videogames, soft robotics, among others.
Anam, K., Al-Jumaily, A. (2012)	Active Exoskeleton Control Systems: State of the Art.	Present the review of control systems in the active exoskeleton existing in the last decade.	The exoskeleton control systems can be categorized according to the model system, physical parameters, hierarchy, and usage. These considerations give different control schemes. The main consideration of the exoskeleton control design is how to achieve the best control performances. However, the stability and safety are other important issued that must be considered.
Mulgaonkar, A., Kornbluh, R., Herr, H. (2008)	Chapter 19 - A new frontier for orthotics and prosthetics: application of dielectric elastomer actuators to bionics.	Analyze the use of dielectric elastomer-based actuators for biomedical use.	Dielectric elastomer actuators (DEAs), whether used as artificial muscles or as replacements for traditional actuators, show great potential for its use in modern active orthotic and prosthetic therapeutic applications. Such actuators are roughly similar in function and biomechanics to natural muscle, including the ability to produce the high maximum power density needed for muscle-like performance.
Stewart, A., Pretty, C., XiaoQi, M. (2017)	Review of Upper Limb Hybrid Exoskeletons.	Provide a general overview of the state of the art of current upper-limb hybrid exoskeletons with a focus on stroke rehabilitation.	This field is still very new and further development of the current control methods used for hybrid skeletons is needed. More research is needed related to the potential benefit of hybrid

			exoskeletons as an assistance tool as required for the patient's monitoring and rehabilitation.
Liu, K., Xiong, C., He, L., Chen, W., Huang, X. (2018)	Postural synergy based design of exoskeleton robot replicating human arm reaching movements	Analyze the reaching movements of human arm by the principal component analysis method.	The configuration of passive joints and balance weights is proposed to improve the performance of the robot. The design method based on the postural synergy is formulated to replicate human arm reaching movements. Finally, tests are taken on the prototype to validate the proposed method. Furthermore, the proposed method can be potentially extended to the design of the robotic arm or manipulator which is only required to perform the specific types of movements.
Kent, B., Lavery, J., Engeberg, E. (2014)	Anthropomorphic Control of a Dexterous Artificial Hand via Task Dependent Temporally Synchronized Synergies.	Propose a control framework which allows the control of an arbitrary number of Degrees of Freedom (DOF) through a single electromyogram (EMG).	After a ten-minute training period, the subjects learned to use the dexterous artificial hand to grasp and catch the cylinder with 100% and 65% average success rate respectively, enabling the subjects to perform both tasks with a dexterous artificial hand using only a single EMG input.
Mak, A., Zhang, M., Leung, A., Prado, M. (2017)	Artificial Limbs	Propose a discussion about prosthetic feet and artificial knee devices as well as biomaterials used for these applications and socket design.	Application of computer technology on prosthetics has improved prosthetic sockets design and manufacturing. Microprocessors have been used for the knee control, such as the Intelligent Knee (Endolite) and the C-Leg (Otto Bock Orthopaedic Industry). Externally powered transtibial prostheses have been developed to restore the lost muscle functions.
Tashiro, H., Popović, M., Dobrev, I, Terasawa, T. (2019)	7 - Artificial Organs, Tissues, and Support Systems.	Address numerous artificial organs, tissues, and support systems already in wide use as well as those that still being actively researched and developed.	Currently, not only material science, electrical and electronic engineering, mechanical engineering but also nanotechnology and tissue engineering are applied to the design of artificial organs.
Huang, Y., Su, S., Song, R. (2020)	7 - Voluntary intention-driven rehabilitation robots for the upper limb.	Propose a new strategy for position-varying compensation of arm gravity for assisting patients whose residual motor ability is restricted by gravity.	The results indicated that, with the proposed gravity compensation strategy, the robot might assist participants to perform higher-quality movements and improve their participation in movements. With the SEMG-based control strategy, the robot could provide appropriate assistance based on participant's voluntary motion and reveal their motor efforts.

Hussain, S, Xie, S, Jamwal, P. (2013)	Control of a robotic orthosis for gait rehabilitation.	Present the new experimental results with an intrinsically compatible gait training robotic orthosis.	A trajectory tracking controller based on the boundary layer augmented sliding control (BASMC) law was implemented to guide the subject's limbs on physiological gait trajectories. Also, the compliance of the robotic orthosis sagittal plane hip and knee joints was controlled, independently of the trajectory tracking control.
Alouane, M., Huo, W., Rifai, H., Amirat, Y., Mohammed, S. (2019)	Hybrid FES-Exoskeleton Controller to Assist Sit-To-Stand movement	Propose a hybrid control approach that combines the use of an impedance-based exoskeleton controller and a Functional Electrical Stimulation (FES) event-based on the knee extensor muscle to assist the STS transfer movement within an assistance strategy as needed.	The obtained performances show the synergy between the assistance provided through FES of the quadriceps muscle during the extension sub-phase of the STS movement and the one delivered by the knee joint actuator od the lower limb exoskeleton.
De Lande, C. (2015)	Welcome to the bionic dawn	Interview with Hugh Herr about his plans to perfectly connect prosthetic devices of next generation to humans.	The BiOM ankle system have normalized walking, speed, and its energy cost. If you simply measure a user's speed and metabolic energy expenditure, you cannot tell whether they have bionic legs or biological legs. That is especially important because conventional technology used on people with leg amputation males them limp, which causes musculoskeletal stresses that lead to joint diseases and many other secondary conditions. True limb bionics eliminate limping and solve these very costly secondary conditions. Typically, when we fit the BiOM prosthesis to a person, if they have hip, knee, or back pain, it is reduced in days.
Kocaoğlu, S., Akdoğan, E (2019)	Design and development of an intelligent biomechatronic tumor prosthesis.	Develop a biomechatronic tumor prosthesis which is able to determine the need for extension by means of its hardware and intelligent control structure	A wireless communication and control system have been created and the performance of the system has been tested on the experimental setup. Limb length discrepancies (LLDs) of 1 mm and above between the healthy limb and the limb with a prosthesis were able to be detected by the system, and prosthesis extension procedure was successfully performed against the maximum soft tissue resistance to be possibly encountered.
Popovic, M.	1 – Introduction.	Serve as principal	Biomechatronics promises to be

(2019)		textbook in a biomechatronics course in the postgraduate and undergraduate since it gives a complete relation between the most popular topics in biomechatronics.	one of the innovative research directions most influential that define the century XXI. Here, a notion of biomechatronics and many topics covered by this (crown) of science and technology, which are briefly reviewed in the context of the material presented in this book.
Simonetti, D.,Tagliamonte, N., Zollo, L., Accoto, D., Guglielmelli, E. (2018)	Chapter 3 - Biomechatronic design criteria of systems for robot-mediated rehabilitation therapy.	Provide an overview on biomechatronic design criteria of generic systems for robot-mediated rehabilitation therapy focused on both the upper and lower limbs.	Basic guidelines on how to build an appropriate model of the human component instrumental for robot design are briefly discussed. Then, criteria for the identification of functional and technical specifications and the selection of key components of the robotic system as a result of the application of a truly biomechatronic approach are introduced. Finally, |two design case studies are presented: (a) the CBM-Motus, a planar robot for upper-limb poststroke rehabilitation, and (b) LENAR, a nonanthropomorphic wearable robot for walking assistance.
Scielo			
Barrios, H., Díaz, V., Guerra, Y. (2020)	Subjetividades e inteligencia artificial: desafíos para 'lo humano'.	Review and interpret the challenges, in terms of benefits, risks, and opportunities of the developments of AI for the subjectivities.	Humanities, in permanent situation of crisis, must strengthen their responses to the new challenges raised by the development of strong AI systems that are related to humanity, its relations, environments, conditions, and nature. Humanities, as the fundamental area in the educational formation, are called to accept and renew the dialogue with developers of new technologies that impact on the human being in its intention to improve it or create an alleged new version.
Martínez, F., Castiblanco, M. (2010)	Proyección, diseño y construcción de plataforma robótica para investigación en inteligencia artificial.	Evaluate autonomous strategies of control, artificial vision, route planning, and collective intelligence.	The projection, design, and construction of a robotic platform for the development and research of applications based on artificial intelligence were presented, aimed to the autonomous robotics. The system's profile was constructed thinking about its use in research related to control autonomous strategies, artificial vision, routes planning, and collective intelligence. Starting from that, its systems of movement, control, sensors,

			power, and mechanical structures were defined and designed. The final platform has a central control unit based on FPGA, able to process complex algorithms, with the possibility to allow the integration of sensors and complex actuators, which ensures the scalability of the tool.
García, E. (2009)	Vida e inteligencia artificial.	Analyze the predictive value of artificial intelligence (AI) in health.	The technological evolution has been very important in the last years. In it, the AI is one of the disciplines with the greatest impact. Its virtual systems allow to predict the dynamic of the healthy and pathologic state of an individual and find solution to the raised virtual problems. The virtual solutions founded could be applied to real health problems; in that way, the cycle of knowledge from real to virtual can be closed to predict the future reality.
Expósito, M., y Ávila, R. (2008)	Aplicaciones de la inteligencia artificial en la Medicina: perspectivas y problemas.	Value the perspectives on use of systems with intelligent behavior in the Cuban medical field.	The application of artificial intelligence in medicine, in addition to requiring a proper delimitation of its goals and tasks, contemplates serious difficulties in the scientific, technological, philosophical, and ethical plans. Despite the effort, its concept is still used in a lot of cases to refer to some simulations of operations by computers considered inherent to man whereas computers with attributes of artificial intelligence are still very limited since they do not perceive the semantics of information and exhibit very poor logical possibilities compared with the ones demonstrated by doctors.
Hernández K., Martínez, A., Béjar, L., y Villagómez, M. (2020)	Análisis Biomecánico de una Prótesis de Cadera mediante Elementos Finitos.	Biomechanical analysis of a hip prosthesis under conditions of static loads associated with daily activities, in which three metallic materials are compared for the production of a personalized prosthesis from medical imaging.	It was observed that doing activities such as jogging and going up and down stairs, materials 316L and L-605 present risk of plastic deformation and, even, breaking. Results showed that the most suitable material for the production of this kind of prosthesis is the Ti-6A1-4V. Moreover, that material allows to make solids and hollow models; this last one signifies a material saving and more lightness in the prosthesis.
Dote, J., Nahuelhual, P., Cubillos, R., Fuentes, G., y	Funcionalidad de prótesis de mano impresa en 3D en adolescentes con	Describe the effect of the prosthesis printed in 3D Cyborg Beast on the functionality of upper	The use of the hand prosthesis Cyborg Beast was not a functional solution for the 5 patients included in the research.

Zuniga, J. (2020)	amputación congénita parcial de mano: Una serie de casos.	limbs in adolescents with partial congenital amputation of the hand.	Future research is necessary to be able to improve the functionality of these prosthesis designs printed in 3D technology.
Broche, L., Torres., M., Milanés., D., González., D., Rodríguez., R., y Sagaró, R. (2020)	Exoesqueleto robótico para la rehabilitación del miembro superior del paciente hemipléjico.	Apply a methodology that integrated design, biomechanical, and clinical criteria in the development of the exoskeleton for the rehabilitation of upper limb in hemiplegic patients.	An integrating methodology was obtained for the development and evaluation in a clinical environment of a robotic exoskeleton for the rehabilitation of the upper limb of a hemiplegic patient, which can be used in the treatment of other strokes and pathologies that affect the upper limb. It is supported by a design process in which biomechanical aspects are integrated, which condition parameters of design and control of the robotic platform with protocols of clinical analysis for the evaluation of the functionality of the rehabilitation equipment.
Oliveros, R., Bonilla, A., Sánchez, R., y Pinilla, R. (2019)	Complicaciones del uso de prótesis metálicas autoexpandibles como paliación de obstrucción maligna del tracto de salida gástrico.	Analyze the complications of the use of the self-expanding metal prostheses as palliation of the malignant gastric outlet obstruction.	Complications of the placement of duodenal prosthesis can be successfully managed by endoscopy in most cases. Patients that, besides the placement of prosthesis, received cancer treatment presented a statistically significant increase in survival.
Alvarado, V., Sánchez, J., Gómez, J., Chihuan, E., y De La Cruz, C. (2019)	Adquisición de señales SEMG con electrodos secos para el control de movimiento de dedos en una prótesis robótica fabricada en una impresora 3D	Comparison between two types of electrodes: wet electrodes (Ag/AgCl) and dry electrodes made of stainless steel, as well as the development of acquisition and SEMG (surface electromyography) signals filtering for the control of a robotic prosthesis for upper limb amputees.	The results of this research will be useful for the development or more advanced prosthesis with common components for people with disabilities, so these people can have a better life quality.
Álvarez C., Lean, P., Rodríguez, R., Pacussich, C., Noriega A., y Navarro, E. (2019)	Desarrollo mecánico y experimental de un implante discal cervical flexible	Develop the geometry and mechanic of a patented disc design, made by additive manufacturing of Titanium-ELI (Extra Low Interstitial), as well as verify its compatibility with the physiology of cervical movements.	The flexible cervical implant made by forging or additive manufacturing of Titanium-ELI presented promising results, which is why its experimental use in patients who had a cervical disc arthroplasty could be proposed.

3. Analysis and discussion of results

Biomechatronics provides a perfect interface and interactions in real time with a biological system and external environment, turning it into a key for automatization services. The result of the literature review consolidates the findings in many groups: in the first group, there are the studies of Lechler et al. (2018); Ulloa, (2018); Novak, (2019); Ruíz et al. (2019); Mulgaonkar et al. (2008); Kent et al. (2014); Mak et al. (20017); Hussain et al. (2013); De Lande (2015); Kocaoğlu and Akdoğan (2019); Hernández et al. (2020); Oliveros et al. (2019) and Álvarez et al. (2019), which evince the positive results of biomechatronic developments (prosthesis and

orthosis) of lower and upper limbs and presenting increased use of applications in upper ones, as well as developing solutions or robotic devices that interact with the human body, nervous system, and muscles.

Likewise, in a second group, the research related to the exoskeleton control systems made by Anam and Al-Jumaily (2012); Stewart et al. (2017); Alouane et al. (2019); Broche et al. (2020) stand out. They asseverate those are structures used to support the body in order to help the individual to heal from an injury or biological disability. According to the literature review, we can classify them into model systems, physical parameters, hierarchy, and use. Moreover, it is stated that the development of hybrid exoskeletons in terms of the rehabilitation of movements after a brain injury must be encouraged and their success is proved in hemiplegic patients and with other pathologies that affect the upper limbs.

Furthermore, the insights of de Liu et al. (2018) and Huang et al. (2020) about the configurations of articulations of the human arm to replicate their movements and the compensation of the gravity of the arm to help patients with residual motor disability. Equivalently, Popovic (2019) and Simonetti et al. (2018) show their contributions about biomechatronics in terms of bachelor's degree and postgraduate studies on their books, giving a general and descriptive perspective on the subject matter and study cases.

Another great contribution to biomechatronics is the one carried out by artificial intelligence, the researchers Barrios et al. (2020), Martínez and Castiblanco (2010), and García (2009) legitimize that humanity must get stronger in the face of crisis situations and consider new challenges. Therefore, it is essential the educational formation in new technologies that impact on human beings and their presumption to optimize and create a new version, which is a presumption for some people and a reality for other ones, as well as find virtual solutions to real problems or predict a future but close reality. However, Expósito and Ávila (2008) raise that if goals and tasks are not properly delimited, serious difficulties in scientific, technological, philosophical, and ethical fields are estimated since the mentioned attributes of the artificial intelligence (AI) do not perceive the semantic of data and show very poor logical events compared with the ones demonstrated by doctors.

In this sense, the solutions printed in 3D stand out, which is a new concept that begins its path in the medical science with poor results so far, but with great perspectives as Dote et al. (2020) and Alvarado et al. (2019) express in their studies by using this technology in hand prosthesis and the control of robotic prosthesis in people with the upper limb with positive results, estimating it can be possible in other body parts to restoring mobility to patients.

Moreover, in the last group resulting from the systematic review, Tashiro et al. (2019) broach the subject matter with nanotechnology and tissue technology to develop artificial organs, which is currently in full development. It is expected that, during the next decade, all organs can be replaced or reconstructed through the mix of different sciences leaded by biomechatronics.

4. Conclusions

The impact of mechatronics on the health field in the last decades has been magnanimous; a great deal of research has been dedicated to develop technology, working with different sciences, in order to correct, rehabilitate, or minimize an individual's disability. Initially, they were oriented to make innovations to contribute to the neuromotor rehabilitation, incorporating robotics and virtual reality and using intelligent machines with a minimum human intervention (Colombo and Sanguineti, 2018).

The notion of the determined artificial therapists was common in the first scientific articles and prototypes. Nevertheless., the new generation of articles introduced the robotic technology (biomechatronics) as a complement and not as a substitute for rehabilitation, including important findings of behavioral studies about sensory-motor adaptation and motor skill learning and its neural substrates.

Therefore, it is necessary to encourage the research since the first university levels in order to create innovations, prototypes, and new technologies that help the human being in the neurorehabilitation, involving neural coding mechanisms from the cellular level to the design of biological and robotic interfaces. Moreover, a large number of books is evinced as a complement for university students and researchers referenced to the subject matter and its futures perspectives in the medium term.

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