



Modern Approaches to Augmentation of Brain Function pp 521–548

[Home](#) > [Modern Approaches to Augmentation of Brain Function](#) > Chapter

Augmentation and Rehabilitation with Active Orthotic Devices

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Abstract

Severe disability, generated to a great extent by nervous and/or musculoskeletal systems' diseases and/or trauma, is a major current health and socioeconomic matter, being a heavy burden—but at the same time, an important challenge for

scientific research—markedly affecting very numerous persons, their kin, and also the communities, worldwide. Additionally, other facts that must be strongly taken into account, on the one hand, are that another considerably sizable bio-/medico-socioeconomic current phenomenon is the accelerated global demographic aging process—a large source of disabled people, too—and on the other hand, that civilized contemporary mentalities' values and care make it a development priority: the endeavors are meant to combat/mitigate disability, thus supporting the affected individuals' personal autonomy, and consequently dignity, and quality of life.

It should be emphasized that by now, at least for the lesions of the central nervous system and for other serious types of abovementioned pathologies, there is no cure. Under these conditions, noninvasive advanced active orthotic devices and connected high technology-assisted interventions represent, even if they are not spectacular judging by outcomes, a contributive emerging domain, as many of them are also involved in pathways to augment brain function. This chapter approaches synthetically the abovementioned modern topic.

Keywords

Augmentation of brain functions

Biofeedback

**Brain-computer interfaces/brain-machine
interfaces/human-machine interfaces**

Disability

Mechatronic/robotic exoskeletons

**Noninvasive advanced active orthotic device-
assisted interventions**

**Neuromuscular electrical
stimulation/functional electrical stimulation**

Quality of life

**Virtual reality/virtual environments/augmented
reality**

Systematic literature review

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References

Abdelkarim E, Brahim SM (2019) Development and control of a low cost Exoskeleton system with an interactive HMI designed for paraplegic children. Int J Sci Eng Res 10(1):4

Adamovich SV, Fluet GG, Tunik E, Merians AS (2009) Sensorimotor training in virtual reality: a review. *NeuroRehabilitation* 25(1):29–44.
<https://doi.org/10.3233/NRE-2009-0497>

Andrikopoulos G, Nikolakopoulos G, Manesis S (2015) Motion control of a novel robotic wrist exoskeleton via pneumatic muscle actuators. In: 2015 IEEE 20th conference on emerging technologies & factory automation (ETFA). IEEE, pp 1–8.
<https://doi.org/10.1109/ETFA.2015.7301464>

Arazpour M, Hutchins SW, Ahmadi Bani M (2015) The efficacy of powered orthoses on walking in persons with paraplegia. *Prosthetics Orthot Int* 39(2):90–99.
<https://doi.org/10.1177/0309364613520031>

Bamodu O, Ye XM (2013) Virtual reality and virtual reality system components. In: *Advanced materials research*, vol 765. Trans Tech Publications Ltd, pp 1169–1172.
<https://doi.org/10.2991/icsem.2013.192>

Banala SK, Kim SH, Agrawal SK, Scholz JP
(2008) Robot assisted gait training with active
leg exoskeleton (ALEX). IEEE Trans Neural Syst
Rehabil Eng 17(1):2–8.

<https://doi.org/10.1109/BIOROB.2008.4762885>

Barsotti M, Leonardis D, Loconsole C, Solazzi M,
Sotgiu E, Procopio C et al (2015) A full upper
limb robotic exoskeleton for reaching and
grasping rehabilitation triggered by MI-BCI. In:
2015 IEEE international conference on
rehabilitation robotics (ICORR). IEEE, pp 49–54.

<https://doi.org/10.1109/ICORR.2015.7281174>

Benford S, Greenhalgh C, Reynard G, Brown C,
Koleva B (1998) Understanding and constructing
shared spaces with mixed-reality boundaries.
ACM Trans Comput Hum Interact 5(3):185–223.

<https://doi.org/10.1145/292834.292836>

Benson I, Hart K, Tussler D, van Middendorp JJ
(2016) Lower-limb exoskeletons for individuals
with chronic spinal cord injury: findings from a
feasibility study. Clin Rehabil 30(1):73–84.

<https://doi.org/10.1177/0269215515575166>

Bouri M, Stauffer Y, Schmitt C, Allemand Y, Gnemmi S, Clavel R et al (2006) The WalkTrainer: a robotic system for walking rehabilitation. In: 2006 IEEE international conference on robotics and biomimetics. IEEE, pp 1616–1621.
<https://doi.org/10.1109/ROBIO.2006.340186>

Bressler SL, Menon V (2010) Large-scale brain networks in cognition: emerging methods and principles. Trends Cogn Sci 14(6):277–290.
<https://doi.org/10.1016/j.tics.2010.04.004>

Buhrman J, Åkesson L (2018) DriVR A driving school simulator in VR. Master Thesis published by: Department of Design Sciences, Faculty of Engineering LTH, Lund University. Lund, Sweden

Buongiorno D, Barsotti M, Barone F, Bevilacqua V, Frisoli A (2018) A linear approach to optimize an EMG-driven neuromusculoskeletal model for movement intention detection in myo-control: a case study on shoulder and elbow joints. Front Neurorobot 12:74.
<https://doi.org/10.3389/fnbot.2018.00074>

Burdea G (2003) Review paper—virtual rehabilitation-benefits and challenges. Yearb Med Inform 1:170–176

Carnahan H (1992) Chapter 8: eye, head and hand coordination during manual aiming. In: Advances in psychology, pp 179–196.
[https://doi.org/10.1016/S0166-4115\(08\)62015-4](https://doi.org/10.1016/S0166-4115(08)62015-4)

Chang S-HJ, Sullivan JL, Kadivar Z, O'Malley M, Francisco GE (2019a) Rehabilitation robotics. In: DeLisa's physical medicine and rehabilitation: principles and practice. Lippincott Williams & Wilkins, Philadelphia, pp 1394–1407

Chang JL, Saul M, Volpe BT (2019b) Practical review of robotics in the treatment of chronic impairment after acquired brain injury. In: Acquired brain injury. Springer, Cham, pp 71–88.
https://doi.org/10.1007/978-3-030-16613-7_5

Charles SK, Krebs HI, Volpe BT, Lynch D, Hogan N (2005) Wrist rehabilitation following stroke: initial clinical results. In: 9th international conference on rehabilitation robotics, 2005. ICORR 2005. IEEE, pp 13–16.
<https://doi.org/10.1109/ICORR.2005.1501040>

Chen G, Chan CK, Guo Z, Yu H (2013) A review of lower extremity assistive robotic exoskeletons in rehabilitation therapy. Crit Rev Biomed Eng 41(4–5):343–363.
<https://doi.org/10.1615/CritRevBiomedEng.2014010453>

Chéron G, Duvinage M, De Saedeleer C, Castermans T, Bengoetxea A, Petieau M et al (2012) From spinal central pattern generators to cortical network: integrated BCI for walking rehabilitation. Neural Plast 2012:375148.
<https://doi.org/10.1155/2012/375148>

Clark WE, Sivan M, O'Connor RJ (2019) Evaluating the use of robotic and virtual reality rehabilitation technologies to improve function in stroke survivors: a narrative review. J Rehabil Assist Technol Eng 6:2055668319863557.
<https://doi.org/10.1177/2055668319863557>

Clus D, Larsen ME, Lemey C, Berrouiguet S (2018) The use of virtual reality in patients with eating disorders: systematic review. J Med Internet Res 20(4):e157.
<https://doi.org/10.2196/jmir.7898>

Contreras-Vidal JL, Bortole M, Zhu F, Nathan K, Venkatakrishnan A, Francisco GE et al (2018) Neural decoding of robot-assisted gait during rehabilitation after stroke. Am J Phys Med Rehabil 97(8):541–550.
<https://doi.org/10.1097/PHM.0000000000000914>

Danielsson I (2009) Method for improving functional recovery after stroke by electrical stimulation of a cranial nerve.
<https://patents.google.com/patent/US9079031>

De Luca R, Maggio MG, Maresca G, Latella D, Cannavò A, Sciarrone F et al (2019) Improving cognitive function after traumatic brain injury: a clinical trial on the potential use of the semi-immersive virtual reality. *Behav Neurol* 2019:9268179.

<https://doi.org/10.1155/2019/9268179>

DeGracia DJ (2010) Towards a dynamical network view of brain ischemia and reperfusion. Part III: therapeutic implications. *J Exp Stroke Transl Med* 3(1):90.

<https://doi.org/10.6030/1939-067X-3.1.90>

Dowling AV, Barzilay O, Lombrozo Y, Wolf A (2014) An adaptive home-use robotic rehabilitation system for the upper body. *IEEE J Transl Eng Health Med* 2:1–10

Duncan PW, Sullivan KJ, Behrman AL, Azen SP, Wu SS, Nadeau SE et al (2011) Body-weight-supported treadmill rehabilitation after stroke. *N Engl J Med* 364(21):2026–2036.

<https://doi.org/10.1056/NEJMoa1010790>

Fan B, Wei Z, Yao X, Shi G, Cheng X, Zhou X et al (2018) Microenvironment imbalance of spinal cord injury. *Cell Transplant* 27(6):853–866.
<https://doi.org/10.1177/0963689718755778>

Fasoli SE, Krebs HI, Hogan N (2004) Robotic technology and stroke rehabilitation: translating research into practice. *Top Stroke Rehabil* 11(4):11–19. <https://doi.org/10.1310/G8XB-VM23-1TK7-PWQU>

Feigin VL, Abajobir AA, Abate KH, Abd-Allah F, Abdulle AM, Abera SF et al (2017) Global, regional, and national burden of neurological disorders during 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet Neurol* 16(11):877–897.
[https://doi.org/10.1016/S1474-4422\(17\)30299-5](https://doi.org/10.1016/S1474-4422(17)30299-5)

Freer DR, Liu J, Yang GZ (2017) Optimization of EMG movement recognition for use in an upper limb wearable robot. In: 2017 IEEE 14th international conference on wearable and implantable body sensor networks (BSN). IEEE, pp 202–205.
<https://doi.org/10.1109/BSN.2017.7936041>

Frisoli A, Solazzi M, Loconsole C, Barsotti M
(2016) New generation emerging technologies
for neurorehabilitation and motor assistance.
Acta Myol 35(3):141

Gandolla M, Costa A, Aquilante L, Gfoehler M,
Puchinger M, Braghin F, Pedrocchi A (2017)
BRIDGE—behavioural reaching interfaces during
daily antigravity activities through upper limb
exoskeleton: preliminary results. In: 2017
international conference on rehabilitation
robotics (ICORR). IEEE, pp 1007–1012.
<https://doi.org/10.1109/ICORR.2017.8009381>

Giberti H, Bertoni V, Coppola G (2014)
Conceptual design and feasibility study of a
novel upper-limb exoskeleton. In: 2014
IEEE/ASME 10th international conference on
mechatronic and embedded systems and
applications (MESA). IEEE, pp 1–6.
<https://doi.org/10.1109/MESA.2014.6935548>

Gijbels D, Lamers I, Kerkhofs L, Alders G, Knippenberg E, Feys P (2011) The Armeo Spring as training tool to improve upper limb functionality in multiple sclerosis: a pilot study. *J Neuroeng Rehabil* 8(1):5.

<https://doi.org/10.1186/1743-0003-8-5>

Gilliaux M, Renders A, Dispa D, Holvoet D, Sapin J, Dehez B et al (2015) Upper limb robot-assisted therapy in cerebral palsy: a single-blind randomized controlled trial. *Neurorehabil Neural Repair* 29(2):183–192.

<https://doi.org/10.1177/1545968314541172>

Grimm F, Walter A, Spüler M, Naros G, Rosenstiel W, Gharabaghi A (2016) Hybrid neuroprosthesis for the upper limb: combining brain-controlled neuromuscular stimulation with a multi-joint arm exoskeleton. *Front Neurosci* 10:367.

<https://doi.org/10.3389/fnins.2016.00367>

Guo S, Gao J, Guo J, Zhang W, Hu Y (2016)
Design of the structural optimization for the
upper limb rehabilitation robot. In: 2016 IEEE
international conference on mechatronics and
automation. IEEE, pp 1185–1190.

<https://doi.org/10.1109/ICMA.2016.7558730>

Haumont T, Rahman T, Sample W, King MM,
Church C, Henley J, Jayakumar S (2011)
Wilmington robotic exoskeleton: a novel device
to maintain arm improvement in muscular
disease. J Pediatr Orthop 31(5):e44–e49.

<https://doi.org/10.1097/BPO.0b013e31821f50b5>

Herold F, Wiegel P, Scholkmann F, Müller NG
(2018) Applications of functional near-infrared
spectroscopy (fNIRS) neuroimaging in exercise–
cognition science: a systematic, methodology–
focused review. J Clin Med 7(12):466.

<https://doi.org/10.3390/jcm7120466>

Hesse S (2007) Treadmill training with partial
body weight support after stroke: a review.
NeuroRehabilitation 22:1–11.

<https://doi.org/10.3233/NRE-2008-23106>. IOS
Press. File: nre394.tex; BOKCTP/wyy p 1

Hesse S, Kuhlmann H, Wilk J, Tomelleri C, Kirker SG (2008) A new electromechanical trainer for sensorimotor rehabilitation of paralysed fingers: a case series in chronic and acute stroke patients. *J Neuroeng Rehabil* 5(1):21.
<https://doi.org/10.1186/1743-0003-5-21>

Hesse S, Waldner A, Tomelleri C (2010) Innovative gait robot for the repetitive practice of floor walking and stair climbing up and down in stroke patients. *J Neuroeng Rehabil* 7(1):30.
<https://doi.org/10.1186/1743-0003-7-30>

Hesse S, Tomelleri C, Bardeleben A, Werner C, Waldner A (2012) Robot-assisted practice of gait and stair climbing in nonambulatory stroke patients. *J Rehabil Res Dev* 49(4):613–622.
<https://doi.org/10.1682/JRRD.2011.08.0142>

Hirano S, Saitoh E, Tanabe S, Katoh M, Shimizu Y, Yatsuya K et al (2015) Comparison between gait-assisting robot (WPAL) and bilateral knee-ankle-foot orthoses with a medial single hip joint in gait reconstruction for patients with paraplegia. *Jpn J Compr Rehabil Sci* 6:21–26.
<https://doi.org/10.11336/jjcrs.6.21>

Hoffman HG, Interface H, Chambers GT, Arceneaux LL, Russell WJ, Seibel EJ et al (2015) Virtual reality as an adjunctive non-pharmacologic analgesic for acute burn pain during medical procedures. *Ann Behav Med* 41(2):183–191. <https://doi.org/10.1007/s12160-010-9248-7>

Hornby TG, Campbell DD, Kahn JH, Demott T, Moore JL, Roth HR (2008) Enhanced gait-related improvements after therapist-versus robotic-assisted locomotor training in subjects with chronic stroke: a randomized controlled study. *Stroke* 39(6):1786–1792. <https://doi.org/10.1161/STROKEAHA.107.504779>

<http://balance-fp7.eu/objectives.php>

http://balance-fp7.eu/project_structure.php

<http://motorika.com/reoambulator/>

<http://prisma-statement.org/documents/PRISMA%202009%20flow%20diagram.pdf>

<http://robots.ihmc.us/x1-mina-exoskeleton>

<http://search.pedro.org.au/search>

http://www.bioness.com/Products/H200_for_Hand_Paralysis/Is_The_H200_Right_For_Me.php

<http://www.exoatlet.com/>

<http://www.indego.com/indego/en/home>

<http://www.motorika.com/optimal-g-pro/>

<https://apps.webofknowledge.com>

<https://asimo.honda.com/innovations/default.aspx?ID=body-weight-support-assist>

<https://bleex.me.berkeley.edu/research/exoskeleton/bleex/>

<https://bleex.me.berkeley.edu/research/exoskeleton/exohiker/>

<https://bleex.me.berkeley.edu/research/exoskeleton/hulc/>

<https://exoskeletonreport.com/2016/09/myopro-the-assistive-arm-exoskeleton-by-myomo-featured-in-solidworks/>

<https://exoskeletonreport.com/product/g-eo-system/>

<https://keeogo.com/success-stories/testimonials>

[https://keeogo.com/walking-aids-for-leg-weakness-or-knee-problems?
keyword=exoskeleton&gclid=EAlaIQobChMlZzxj_oLs5gIVy5AYCh0tfgCdEAAYASAAEgKIFPD_BwE](https://keeogo.com/walking-aids-for-leg-weakness-or-knee-problems?keyword=exoskeleton&gclid=EAlaIQobChMlZzxj_oLs5gIVy5AYCh0tfgCdEAAYASAAEgKIFPD_BwE)

<https://myomo.com/what-is-a-myopro-orthosis/>

<https://peteredwards2012.wordpress.com/ekso-bionics-elegs/>

<https://walk-again-project.org/#/en>

<https://www.alterg.com/anti-gravity-treadmills>

<https://www.cadencebiomedical.com>

<https://www.cadth.ca/sites/default/files/pdf/htis/july-2015/RA0784%20Powered%20Wearable%20Walking%20Assistive%20Devices%20Final.pdf>

https://www.cyberdyne.jp/english/products/LowerLimb_medical.html

<https://www.cyberdyne.jp/english/products/supporting.html>

<https://www.elsevier.com/>

https://www.e-information.ro/resurse/bnr_thomson-reuters,
https://www.e-information.ro/resurse/bnr_thomson-reuters

<https://www.frontiersin.org/articles/10.3389/fnins.2018.00577/full#supplementary-material>

<https://www.hocoma.com/solutions/lokomat/>

<https://www.honda.com/mobility/walking-assist-technology>

https://www.medgadget.com/2006/07/autoambulator_r.html

<https://www.ncbi.nlm.nih.gov>

<https://www.rexbionics.com>

<https://www.technaid.com/products/robotic-exoskeleton-exo-exoesqueleto/>

<https://www.technaid.com/products/robotic-exoskeleton-exo-exoesqueleto-h3/>

<https://www.utwente.nl/en/et/be/research/projects/MINDWALKER/>

<https://www.youtube.com/watch?v=76sF3rsHMYo>

Huang S, Luo C, Ye S, Liu F, Xie B, Wang C et al (2012) Motor impairment evaluation for upper limb in stroke patients on the basis of a microsensor. Int J Rehabil Res 35(2):161–169.
<https://doi.org/10.1097/MRR.0b013e328353053a>

Janssen J, Verschuren O, Renger WJ, Ermers J, Ketelaar M, van Ee R (2017) Gamification in physical therapy: more than using games. Pediatr Phys Ther 29(1):95–99.
<https://doi.org/10.1097/PEP.0000000000000326>

Jung JH, Lee HJ, Cho DY, Lim JE, Lee BS, Kwon SH et al (2019) Effects of combined upper limb robotic therapy in patients with tetraplegic spinal cord injury. Ann Rehabil Med 43(4):445

Kagawa T, Uno Y (2009) Gait pattern generation for a power-assist device of paraplegic gait. In: RO-MAN 2009—the 18th IEEE international symposium on robot and human interactive communication. IEEE, pp 633–638.

<https://doi.org/10.1109/ROMAN.2009.5326348>

Kannape OA, Lenggenhager B (2016) Engineered embodiment: comment on “the embodiment of assistive devices—from wheelchair to exoskeleton” by M. Pazzaglia and M. Molinari. *Phys Life Rev* 16:181–183.

<https://doi.org/10.1016/j.plrev.2016.01.011>

Kawase T, Sakurada T, Koike Y, Kansaku K (2017) A hybrid BMI-based exoskeleton for paresis: EMG control for assisting arm movements. *J Neural Eng* 14(1):016015.

<https://doi.org/10.1088/1741-2552/aa525f>

Kiguchi K, Rahman MH, Sasaki M, Teramoto K (2008) Development of a 3DOF mobile exoskeleton robot for human upper-limb motion assist. *Robot Auton Syst* 56(8):678–691.

<https://doi.org/10.1016/j.robot.2007.11.007>

Kim H, Rosen J (2015) Predicting redundancy of a 7 dof upper limb exoskeleton toward improved transparency between human and robot. *J Intell Robot Syst* 80(1):99–119.

<https://doi.org/10.1007/s10846-015-0212-4>

Kim H, Miller LM, Fedulow I, Simkins M, Abrams GM, Byl N, Rosen J (2012) Kinematic data analysis for post-stroke patients following bilateral versus unilateral rehabilitation with an upper limb wearable robotic system. *IEEE Trans Neural Syst Rehabil Eng* 21(2):153–164.

<https://doi.org/10.1109/TNSRE.2012.2207462>

Knutson JS, Sheffer LR, Chae J (2010) Functional neuromuscular electrical stimulation (Chapter 72). In: Frontera WR, DeLisa JA (eds) *DeLisa's physical medicine & rehabilitation principles and practice*. Wolters Kluwer Health/Lippincott Williams & Wilkins, Philadelphia, pp 1977–1996

Knutson JS, Brose SW, Plow EB et al (2020) Electrical stimulation (therapeutic and functional). In: Frontera WR, DeLisa JA (eds) DeLisa's physical medicine and rehabilitation: principles and practice. Wolters Kluwer Health/Lippincott Williams & Wilkins, Philadelphia, pp 1246–1263

Ko HY (2019) Management and rehabilitation of spinal cord injuries. Springer, Singapore

Kolakowsky-Hayner SA, Crew J, Moran S, Shah A (2013) Safety and feasibility of using the Ekso™ bionic exoskeleton to aid ambulation after spinal cord injury. J Spine 4(3).

<https://doi.org/10.4172/2165-7939.s4-003>

Kordower JH, Tuszynski MH (2008) CNS regeneration: basic science and clinical advances. Elsevier.

<https://www.sciencedirect.com/science/book/9780123739940>

Kwak NS, Müller KR, Lee SW (2015) A lower limb exoskeleton control system based on steady state visual evoked potentials. *J Neural Eng* 12(5):056009. <https://doi.org/10.1088/1741-2560/12/5/056009>

Lajeunesse V, Vincent C, Routhier F, Careau E, Michaud F (2016) Exoskeletons' design and usefulness evidence according to a systematic review of lower limb exoskeletons used for functional mobility by people with spinal cord injury. *Disabil Rehabil Assist Technol* 11(7):535–547. <https://doi.org/10.3109/17483107.2015.1080766>

Lebedev M (2014) Brain-machine interfaces: an overview. *Transl Neurosci* 5(1):99–110. <https://doi.org/10.2478/s13380-014-0212-z>

Li R, Hu XL, Tong KY (2008) Combined electromyography (EMG)-driven system with functional electrical stimulation (FES) for poststroke rehabilitation. In: 2008 2nd IEEE RAS & EMBS international conference on biomedical robotics and biomechatronics. IEEE, pp 642–646 <https://doi.org/10.1109/BIOROB.2008.4762821>

Liepert J, Bauder H, Miltner WH, Taub E, Weiller C (2000) Treatment-induced cortical reorganization after stroke in humans. *Stroke* 31(6):1210–1216.

<https://doi.org/10.1161/01.STR.31.6.1210>

López NM, de Diego N, Hernández R, Pérez E, Ensínck G, Valentinuzzi ME (2014) Customized device for pediatric upper limb rehabilitation in obstetric brachial palsy. *Am J Phys Med Rehabil* 93(3):263–266.

<https://doi.org/10.1097/PHM.0b013e3182a51c95>

Louie DR, Eng JJ (2016) Powered robotic exoskeletons in post-stroke rehabilitation of gait: a scoping review. *J Neuroeng Rehabil* 13(1):53.

<https://doi.org/10.1186/s12984-016-0162-5>

Louie DR, Eng JJ, Lam T (2015) Gait speed using powered robotic exoskeletons after spinal cord injury: a systematic review and correlational study. *J Neuroeng Rehabil* 12(1):82.

<https://doi.org/10.1186/s12984-015-0074-9>

Ma M, Zheng H (2011) Virtual reality and serious games in healthcare. In: Advanced computational intelligence paradigms in healthcare 6. Virtual reality in psychotherapy, rehabilitation, and assessment. Springer, Berlin, pp 169–192

Maciejasz P, Eschweiler J, Gerlach-Hahn K, Jansen-Troy A, Leonhardt S (2014) A survey on robotic devices for upper limb rehabilitation. J Neuroeng Rehabil 11(1):3

Marchal-Crespo L, Reinkensmeyer DJ (2009) Review of control strategies for robotic movement training after neurologic injury. J Neuroeng Rehabil 6(1):20.
<https://doi.org/10.1186/1743-0003-6-20>

Martín-Gutiérrez J, Mora CE, Añorbe-Díaz B, González-Marrero A (2017) Virtual technologies trends in education. EURASIA J Math Sci Technol Educ 13(2):469–486.
<https://doi.org/10.12973/eurasia.2017.00626a>

Mavroidis C, Nikitczuk J, Weinberg B, Arango R, Danaher G, Jensen K et al (2005) Smart portable rehabilitation devices. In: International design engineering technical conferences and computers and information in engineering conference, vol 47446, pp 501–510.

<https://doi.org/10.1186/1743-Received>

Mazzoleni S, Duret C, Grosmaire AG, Battini E (2017) Combining upper limb robotic rehabilitation with other therapeutic approaches after stroke: current status, rationale, and challenges. *BioMed Res Int* 2017.

<https://doi.org/10.1155/2017/8905637>

Mazzoleni S, Battini E, Crecchi R, Dario P, Posteraro F (2018) Upper limb robot-assisted therapy in subacute and chronic stroke patients using an innovative end-effector haptic device: a pilot study. *NeuroRehabilitation* 42(1):43–52.

<https://doi.org/10.3233/NRE-172166>

Michmizos KP, Krebs HI (2012) Serious games for the pediatric anklebot. In: 2012 4th IEEE RAS & EMBS international conference on biomedical robotics and biomechatronics (BioRob). IEEE, pp 1710–1714.

<https://doi.org/10.1109/BioRob.2012.6290706>

Milia P, Peccini MC, De Salvo F, Sfaldaroli A, Grelli C, Lucchesi G et al (2019) Rehabilitation with robotic glove (Gloreha) in poststroke patients. Digit Med 5(2):62.

https://doi.org/10.4103/digm.digm_3_19

Mironov VI, Kastalskiy I, Lobov S, Kazantsev VB (2017) A biofeedback control system of the exoskeleton trainer for lower limbs motor function recovery. In: NEUROTECHNIX. pp 54–59. <https://doi.org/10.5220/0006584700540059>

Montana JI, Tuena C, Serino S, Cipresso P, Riva G (2019) Neurorehabilitation of spatial memory using virtual environments: a systematic review. J Clin Med 8(10):1516.

<https://doi.org/10.3390/jcm8101516>

Muresanu DF, Buzoianu A, Florian SI, von Wild T (2012) Towards a roadmap in brain protection and recovery. *J Cell Mol Med* 16(12):2861–2871.
<https://doi.org/10.1111/j.1582-4934.2012.01605.x>

Nagarajan U, Goswami A (2015) Improved mobility with a neutral, motion-amplifying controller for an experimental exoskeleton. *SAE Int J Passeng Cars Mech Syst* 8(2):606–613.
<https://doi.org/10.4271/2015-01-1400>

Neugebauer J (2017) Robotics/exoskeleton/augmentation definitions and taxonomy. pp 1–16.
https://www.nist.gov/system/files/documents/2017/02/06/2a._nist_taxonomy_and_definitions_v2.pdf

Nicolelis MA, Lebedev MA (2009) Principles of neural ensemble physiology underlying the operation of brain–machine interfaces. *Nat Rev Neurosci* 10(7):530–540.
<https://doi.org/10.1038/nrn2653>

Nimawat D, Jailiya PRS (2015) Requirement of wearable robots in current scenario. *Eur J Adv Eng Technol* 2(2):19–23

Norouzi-Gheidari N, Archambault PS, Fung J (2012) Effects of robot-assisted therapy on stroke rehabilitation in upper limbs: systematic review and meta-analysis of the literature. *J Rehabil Res Dev* 49(4):479–496.

<https://doi.org/10.1682/JRRD.2010.10.0210>

Noveanu S, Chetran B, Tatar O, Raducanu G, Mândru D (2013) Structural synthesis of the upper limb modular wearable exercisers. In: 2013 17th international conference on system theory, control and computing (ICSTCC). IEEE, pp 693–698

Nycz CJ, Delph MA, Fischer GS (2015) Modeling and design of a tendon actuated soft robotic exoskeleton for hemiparetic upper limb rehabilitation. In: 2015 37th annual international conference of the IEEE engineering in medicine and biology society (EMBC). IEEE, pp 3889–3892.

<https://doi.org/10.1109/EMBC.2015.7319243>

Onose G, Grozea C, Anghelescu A, Daia C, Sinescu CJ, Ciurea AV et al (2012) On the feasibility of using motor imagery EEG-based brain–computer interface in chronic tetraplegics for assistive robotic arm control: a clinical test and long-term post-trial follow-up. *Spinal Cord* 50(8):599–608.

<https://doi.org/10.1038/sc.2012.14>

Onose G, Cârdei V, Crăciunoiu ȘT, Avramescu V, Opriș I, Lebedev MA, Constantinescu MV (2016) Mechatronic wearable exoskeletons for bionic bipedal standing and walking: a new synthetic approach. *Front Neurosci* 10:343.

<https://doi.org/10.3389/fnins.2016.00343>

Onose G, Popescu N, Munteanu C, Ciobanu V, Sporea C, Mirea MD et al (2018) Mobile mechatronic/robotic orthotic devices to assist–rehabilitate neuromotor impairments in the upper limb: a systematic and synthetic review. *Front Neurosci* 12:577.

<https://doi.org/10.3389/fnins.2018.00577>

Palermo AE, Maher JL, Baunsgaard CB, Nash MS (2017) Clinician-focused overview of bionic exoskeleton use after spinal cord injury. *Top Spinal Cord Inj Rehabil* 23(3):234–244.
<https://doi.org/10.1310/sci2303-234>

Parker J, Sherwood M, Kane J (2013) A real-time functional magnetic resonance imaging (fMRI) neurofeedback system. *IFAC Proc* 46(15):341–348. <https://doi.org/10.3182/20130811-5-US-2037.00078>

Pelz J, Hayhoe M, Loeber R (2001) The coordination of eye, head, and hand movements in a natural task. *Exp Brain Res* 139(3):266–277.
<https://doi.org/10.1007/s002210100745>

Pirondini E, Coscia M, Marcheschi S, Roas G, Salsedo F, Frisoli A et al (2014) Evaluation of a new exoskeleton for upper limb post-stroke neuro-rehabilitation: preliminary results. In: *Replace, repair, restore, relieve—bridging clinical and engineering solutions in neurorehabilitation*. Springer, Cham, pp 637–645.
<https://doi.org/10.1007/978-3-319-08072-7>

Presacco A, Forrester LW, Contreras-Vidal JL
(2012) Decoding intra-limb and inter-limb
kinematics during treadmill walking from scalp
electroencephalographic (EEG) signals. IEEE
Trans Neural Syst Rehabil Eng 20(2):212–219

Proietti T, Crocher V, Roby-Brami A, & Jarrassé N
(2016) Upper-limb robotic exoskeletons for
neurorehabilitation: a review on control
strategies. IEEE reviews in biomedical
engineering,9:4–14

Rahman T, Sample W, Jayakumar S, King MM
(2006) Passive exoskeletons for assisting limb
movement. J Rehabil Res Dev 43(5):583.
<https://doi.org/10.1682/JRRD.2005.04.0070>

Rego P, Moreira PM, Reis LP (2010) Serious
games for rehabilitation: a survey and a
classification towards a taxonomy. In: 5th Iberian
conference on information systems and
technologies. IEEE, pp 1–6

Reinkensmeyer DJ, Aoyagi D, Emken JL, Galvez JA, Ichinose W, Kerdanyan G et al (2014) Tools for understanding and optimizing robotic gait training. J Rehabil Res Dev 43(5):657–670.

<https://doi.org/10.1682/JRRD.2005.04.0073>

Ring H, Rosenthal N (2005) Controlled study of neuroprosthetic functional electrical stimulation in sub-acute post-stroke rehabilitation. J Rehabil Med 37(1):32–36.

<https://doi.org/10.1080/16501970410035387>

Robinson NL, Cottier TV, Kavanagh DJ (2019) Psychosocial health interventions by social robots: systematic review of randomized controlled trials. J Med Internet Res 21(5):e13203. <https://doi.org/10.2196/13203>

Rocon E, Belda-Lois JM, Ruiz AF, Manto M, Moreno JC, Pons JL (2007) Design and validation of a rehabilitation robotic exoskeleton for tremor assessment and suppression. IEEE Trans Neural Syst Rehabil Eng 15(3):367–378.

<https://doi.org/10.1109/TNSRE.2007.903917>

Sheffer LR, Knutson JS, Chae J (2010)
Therapeutic electrical stimulation in
neurorehabilitation (Chapter 71). In: Frontera WR,
DeLisa JA (eds) DeLisa's physical medicine and
rehabilitation: principles and practice. Wolters
Kluwer Health/Lippincott Williams & Wilkins,
Philadelphia, pp 1953–1975

Sheridan TB (1992) Musings on telepresence
and virtual presence. *Presence* 1(1):120–126.
<https://doi.org/10.1162/pres.1992.1.1.120>

Shull PB, Damian DD (2015) Haptic wearables as
sensory replacement, sensory augmentation and
trainer—a review. *J Neuroeng Rehabil* 12(1):59.
<https://doi.org/10.1186/s12984-015-0055-z>

Sisto SA, Forrest GF, Glendinning D (2002)
Virtual reality applications for motor rehabilitation
after stroke. *Top Stroke Rehabil* 8(4):11–23

Soiza-Reilly M, Saggau P, Arenkiel BR (2015)
Neural circuits revealed. *Front Neural Circuits*
9:35. <https://doi.org/10.3389/fncir.2015.00035>

Song Z, Guo S, Xiao N, Gao B, Shi L (2012) Implementation of human-machine synchronization control for active rehabilitation using an inertia sensor. *Sensors* 12(12):16046–16059. <https://doi.org/10.3390/s121216046>

Song Z, Guo S, Pang M, Zhang S, Xiao N, Gao B, Shi L (2014) Implementation of resistance training using an upper-limb exoskeleton rehabilitation device for elbow joint. *J Med Biol Eng* 34(2):188–196. <https://doi.org/10.5405/jmbe.1337>

Stein J (2009) e100 NeuroRobotic system. *Expert Rev Med Devices* 6(1):15–19. <https://doi.org/10.1586/17434440.6.1.15>

Stein J (2019) Stroke. In: Frontera W, Silver J, Rizzo T (eds) *Essentials of physical medicine and rehabilitation: musculoskeletal disorders, pain, and rehabilitation*. Elsevier, Philadelphia, pp 931–936

Stewart AM, Pretty CG, Adams M, Chen X (2017) Review of upper limb hybrid exoskeletons. IFAC-Papers Online 50(1):15169–15178.

<https://doi.org/10.1016/j.ifacol.2017.08.2266>

Takizawa S, Wada R, Tachibana T et al (2018) Implementation and result of the takizawa method to the outpatient rehabilitation facility and evaluation of the brain activity by fNIRS. J Clin Diagn Treat 1:26–31

Tarkka IM, Hautasaari P (2019) Motor action execution in reaction-time movements: magnetoencephalographic study. Am J Phys Med Rehabil 98(9):771–776.

<https://doi.org/10.1097/PHM.0000000000001187>

Thielbar KO, Triandafilou KM, Fischer HC, O'Toole JM, Corrigan ML, Ochoa JM et al (2016) Benefits of using a voice and EMG-driven actuated glove to support occupational therapy for stroke survivors. IEEE Trans Neural Syst Rehabil Eng 25(3):297–305.

<https://doi.org/10.1109/TNSRE.2016.2569070>

Tu X, Han H, Huang J, Li J, Su C, Jiang X, He J (2017) Upper limb rehabilitation robot powered by PAMs cooperates with FES arrays to realize reach-to-grasp trainings. J Healthc Eng 2017:1282934.

<https://doi.org/10.1155/2017/1282934>

Veneman JF (2014) Exoskeletons supporting postural balance—the balance project. In: Replace, repair, restore, relieve—bridging clinical and engineering solutions in neurorehabilitation. Springer, Cham, pp 203–208.

https://doi.org/10.1007/978-3-319-08072-7_38

Veneman JF, Kruidhof R, Hekman EE, Ekkelenkamp R, Van Asseldonk EH, Van Der Kooij H (2007) Design and evaluation of the LOPES exoskeleton robot for interactive gait rehabilitation. IEEE Trans Neural Syst Rehabil Eng 15(3):379–386.

<https://doi.org/10.1109/TNSRE.2007.903919>

Watson T (2007) Transcutaneous Electrical Nerve Stimulation (TENS).

<http://www.electrotherapy.org/modality/transcutaneous-electrical-nerve-stimulation-tens>

Watts LT, Long JA, Manga VH, Huang S, Shen Q, Duong TQ (2015) Normobaric oxygen worsens outcome after a moderate traumatic brain injury. *J Cereb Blood Flow Metab* 35(7):1137–1144.

<https://doi.org/10.1038/jcbfm.2015.18>

Weber DJ, Skidmore ER, Niyonkuru C, Chang CL, Huber LM, Munin MC (2010) Cyclic functional electrical stimulation does not enhance gains in hand grasp function when used as an adjunct to onabotulinumtoxinA and task practice therapy: a single-blind, randomized controlled pilot study. *Arch Phys Med Rehabil* 91(5):679–686.

<https://doi.org/10.1016/j.apmr.2010.01.010>

Weber LM, Nilsen DM, Gillen G, Yoon J, Stein J (2019) Immersive virtual reality mirror therapy for upper limb recovery after stroke: a pilot study. *Am J Phys Med Rehabil* 98(9):783–788.

<https://doi.org/10.1097/PHM.0000000000001190>

[0](https://doi.org/10.1097/PHM.0000000000001190)

Wei W, Guo S, Zhang F, Guo J, Ji Y, Wang Y (2013a) A novel upper limb rehabilitation system with hand exoskeleton mechanism. In: 2013 IEEE international conference on mechatronics and automation. IEEE, pp 285–290.

<https://doi.org/10.1109/ICMA.2013.6617932>

Wei W, Guo S, Zhang W, Guo J, Wang Y (2013b) A novel VR-based upper limb rehabilitation robot system. In: 2013 ICME international conference on complex medical engineering. IEEE, pp 302–306.

<https://doi.org/10.1109/ICCME.2013.6548259>

Weidig C, Mestre DR, Israel JH, Noel F, Perrot V, Aurich JC (2014) Classification of VR interaction techniques, based on user intention.

Eurographics Digital Library.

<https://doi.org/10.2312/eurovr.20141339>

Weiskopf N, Mathiak K, Bock SW, Scharnowski F, Veit R, Grodd W et al (2004) Principles of a brain-computer interface (BCI) based on real-time functional magnetic resonance imaging (fMRI). IEEE Trans Biomed Eng 51(6):966–970.

<https://doi.org/10.1109/TBME.2004.827063>

Widmer M (2018) Research collection,
(November). <https://doi.org/10.3929/ethz-a-010870008>

Xiao ZG, Elnady AM, Webb J, Menon C (2014)
Towards a brain computer interface driven
exoskeleton for upper extremity rehabilitation. In:
5th IEEE RAS/EMBS international conference on
biomedical robotics and biomechatronics. IEEE,
pp 432–437.
<https://doi.org/10.1109/biorob.2014.6913815>

Yatsuya K, Hirano S, Saitoh E, Tanabe S, Tanaka
H, Eguchi M et al (2018) Comparison of energy
efficiency between wearable power-assist
locomotor (WPAL) and two types of knee-ankle-
foot orthoses with a medial single hip joint
(MSH-KAFO). J Spinal Cord Med 41(1):48–54.
<https://doi.org/10.1080/10790268.2016.1226701>

Yoshimoto T, Shimizu I, Hiroi Y, Kawaki M, Sato D, Nagasawa M (2015) Feasibility and efficacy of high-speed gait training with a voluntary driven exoskeleton robot for gait and balance dysfunction in patients with chronic stroke: nonrandomized pilot study with concurrent control. *Int J Rehabil Res* 38(4):338–343.

<https://doi.org/10.1097/MRR.0000000000000132>

2

Young W, AlZoubi ZM, Saberi H, Sharma A, Muresanu D, Feng S, Chen L, Huang H (2015) Beijing declaration of international association of neurorestoratology. *Journal of Neurorestoratology* 3: 121–122

Zeilig G, Weingarden H, Zwecker M, Dudkiewicz I, Bloch A, Esquenazi A (2012) Safety and tolerance of the ReWalk™ exoskeleton suit for ambulation by people with complete spinal cord injury: a pilot study. *J Spinal Cord Med* 35(2):96–101.

<https://doi.org/10.1179/2045772312Y.0000000003>

03

Zhou X, He X, Ren Y (2014) Function of microglia and macrophages in secondary damage after spinal cord injury. *Neural Regen Res* 9(20):1787. <https://doi.org/10.4103/1673-5374.143423>

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All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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No conflicts of interest: the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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