Available online at www.sciencedirect.com

ScienceDirect

Physics of Life Reviews 16 (2016) 163–175

PHYSICS of LIFE reviews

www.elsevier.com/locate/plrev

Review

The embodiment of assistive devices—from wheelchair to exoskeleton

Mariella Pazzaglia [a,b,*], Marco Molinari [b]

[a] *Department of Psychology, University of Rome 'La Sapienza', Via dei Marsi 78, 00185 Rome, Italy*
[b] *IRCCS Fondazione Santa Lucia, Via Ardeatina 306, 00179 Rome, Italy*

Received 24 November 2015; accepted 24 November 2015

Available online 2 December 2015

Communicated by J. Fontanari

Abstract

Spinal cord injuries (SCIs) place a heavy burden on the healthcare system and have a high personal impact and marked socio-economic consequences. Clinically, no absolute cure for these conditions exists. However, in recent years, there has been an increased focus on new robotic technologies that can change the frame we think about the prognosis for recovery and for treating some functions of the body affected after SCIs. This review has two goals. The first is to assess the possibility of the embodiment of functional assistive tools after traumatic disruption of the neural pathways between the brain and the body. To this end, we will examine how altered sensorimotor information modulates the sense of the body in SCI. The second goal is to map the phenomenological experience of using external tools that typically extend the potential of the body physically impaired by SCI. More specifically, we will focus on the difference between the perception of one's physically augmented and non-augmented affected body based on observable and measurable behaviors. We discuss potential clinical benefits of enhanced embodiment of the external objects by way of multisensory interventions. This review argues that the future evolution of human robotic technologies will require adopting an embodied approach, taking advantage of brain plasticity to allow bionic limbs to be mapped within the neural circuits of physically impaired individuals.

Keywords: Body representation; Embodiment; Neuroprosthetic technology; Robotic exoskeleton; Spinal cord injury

1. Introduction

The young Brazilian with paraplegia striking the first kick of the 2014 FIFA World Cup and the two patients of the Santa Lucia Foundation who ran one kilometer of the 2015 Rome marathon while wearing an exoskeleton were powerful reflections of the psychological and emotional experience of standing and walking again: walking,

* Corresponding author at: Dipartimento di Psicologia, Università di Roma "La Sapienza", Via dei Marsi 78, 00185, Roma, Italy. Tel.: +39 6 49917526; fax: +39 6 4451667.

E-mail address: mariella.pazzaglia@uniroma1.it (M. Pazzaglia).

http://dx.doi.org/10.1016/j.plrev.2015.11.006
1571-0645/

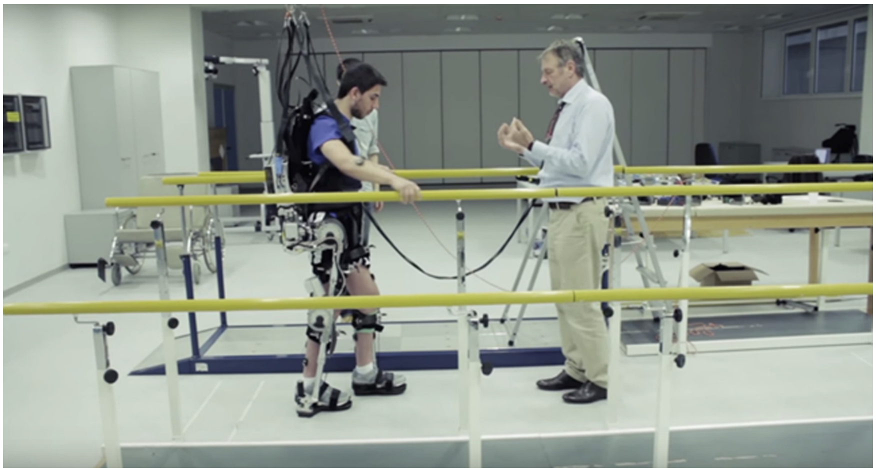

Fig. 1. Exoskeleton for gait rehabilitation. A patient with spinal cord injury wearing the MINDWALKER exoskeleton during rehabilitation training for locomotion disorder.

ran even playing soccer, could be possible for people with paraplegia in future. Spinal cord injuries (SCIs) place a heavy burden on the healthcare system and have a high personal impact and marked socio-economic consequences [1]. Approximately 2–3 million people worldwide experience full or partial paralysis and reduced sensitivity due to SCI [2], with thousands of new traumatic injuries occurring each year [3]. Predominantly, these injuries occur in individuals under the age of 30 [4]. In SCI, the sensorimotor signaling between the body and the brain is interrupted and becomes damaged permanently.

Depending on the location and the extent of the spinal cord lesion, individuals with SCI eventually have severe movement and sensation disabilities in body segments located downwards from the level of the injury. Generally, injury to the upper level of the cervical spinal cord, known as tetraplegia, causes sensory loss and paralysis in the relevant areas of the upper and lower body. If instead the lesion is at a lower level, i.e., thoracic or lumbar, it results in loss of sensation in or voluntary movement of the lower body, specifically, and is referred to as paraplegia. In addition, spinal cord injuries increase the risk of several secondary medical consequences [5].

Clinically, no absolute cure for these conditions exists at present [6]. Functional recovery of paralyzed limbs has a high priority in the rehabilitation treatment of patients with SCI [7–9]. Neural approaches to promote the regeneration of descending circuits and the repair of cellular and molecular mechanisms within the injured spinal cord are in development [10–13]. Despite the important advances in methods and approaches for tissue regeneration [14], including the use of stem cells, this research is still far from being ready for translation into clinically effective treatments [15,16]. However, in recent years, there has been an increased focus on new sophisticated technologies that can change the way we think about the prognosis for recovery and for treating some of the body functions affected by SCIs. Researchers are exploring ways to stimulate muscles directly via electrodes inserted into the spinal cord or brain system [17–20]. In addition to these stimulation approaches, biotechnology studies have been investigating the use of robotic legs for addressing paralysis due to SCIs. Exoskeletons incorporate light-weight, wearable electrically-powered joints which mimic their affected biological counterparts and thus extend the patient's functional body. Exoskeletons based on innovative medical technology, acquire the wearer's motion intentions, integrate to: i) assist the wearer's locomotion (Fig. 1); ii) enhance the strength of the wearer's joints; and iii) achieve a high level of performance in rehabilitation [21].

Several complex lower limb exoskeletons are commercially available, and others are in the prototype stage [22–31]. These are clinically applicable and offer renewed hope for immobile individuals [32]. These assistive devices offer the possibility, at least in principle, of partial recovery or substituting the functionality of the damaged body part. Substantial advancement has been made in terms of safety, portability, skills, and effort required for use of such exoskeletons [24,30], but little progress has been achieved in terms of active control of the actions of the robotic assisted limb and of sensing it. These concerns are particularly relevant for assistive devices that support the morphology of affected counterpart and connect directly to the body [33]. The challenges of technology must, however, be overcome before these new robotic legs can be broadly applied [34–37].