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Literature review / Revue de la littérature

Innovative technologies applied to sensorimotor rehabilitation after stroke

Technologies nouvelles appliquées à la rééducation sensori-motrice après AVC

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Abstract

Innovative technologies for sensorimotor rehabilitation after stroke have dramatically increased these past 20 years. Based on a review of the literature on ''Medline'' and ''Web of Science'' between 1990 and 2013, we offer an overview of available tools and their current level of validation. Neuromuscular electric stimulation and/or functional electric stimulation are widely used and highly suspected of being effective in upper or lower limb stroke rehabilitation. Robotic rehabilitation has yielded various results in the literature. It seems to have some effect on functional capacities when used for the upper limb. Its effectiveness in gait training is more controversial. Virtual reality is widely used in the rehabilitation of cognitive and motor impairments, as well as posture, with admitted benefits. Non-invasive brain stimulation (rTMS and TDCS) are promising in this indication but clinical evidence of their effectiveness is still lacking. In the same manner, these past five years, neurofeedback techniques based on brain signal recordings have emerged with a special focus on their therapeutic relevance in rehabilitation. Technological devices applied to rehabilitation are revolutionizing our clinical practices. Most of them are based on advances in neurosciences allowing us to better understand the phenomenon of brain plasticity, which underlies the effectiveness of rehabilitation. The acceptation and ''real use'' of those devices is still an issue since most of them are not easily available in current practice.

Keywords: Stroke; Rehabilitation; New technologies; Robotics; Virtual reality; Brain stimulation

Résumé

Les technologies innovantes appliquées à la rééducation sensori-motrice dans les suites d'un accident vasculaire cérébral se sont multipliées ces 20 dernières années. À partir d'une revue de la littérature sur « Medline » et « Web of Science » entre 1990 et 2013, nous proposons une synthèse des outils disponibles et de leur niveau de validation actuel. La stimulation électrique neuromusculaire et/ou fonctionnelle a une efficacité admise dans cette indication. La robotique de rééducation a été diversement appréciée dans la littérature. Il semble qu'elle ait une certaine efficacité sur les capacités fonctionnelles lorsqu'elle est utilisée pour le membre supérieur. Son efficacité dans la rééducation à la marche est plus controversée. La réalité virtuelle est utilisée par de nombreuses équipes dans la rééducation de la motricité ou de la posture, avec un bénéfice maintenant admis. Les techniques de stimulations cérébrales non invasives (rTMS et TDCS) sont encore exploratoires dans cette indication, de la même façon que les techniques de neuro-feedback visant à utiliser l'enregistrement du signal cérébral pour agir sur la plasticité cérébrale. L'avènement de ces technologies appliquées à la rééducation est en train de révolutionner nos pratiques. Elles reposent sur les progrès des neurosciences qui nous permettent de mieux comprendre les phénomènes de plasticité neurale qui sous-tendent l'efficacité de la rééducation. L'appropriation de ces outils

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par les patients et les thérapeutes est une nécessité. Ces dispositifs doivent se mettre au service de la relation entre le patient et son rééducateur mais ne peuvent se substituer à ce dernier.

Mots clés : Accident vasculaire cérébral ; Rééducation ; Technologies nouvelles ; Robotique ; Réalité virtuelle ; Stimulation cérébrale

1. English version

1.1. Introduction

The rehabilitation of hemiplegic patients has greatly improved these past 30 years [1]. New organization models have been proposed, from the creation of specialized units [2], to the concepts of ''early supported discharge'' [3], ''tele-rehabilitation'' [4,5] and ''self-rehabilitation'' [6].

Alongside these organizational evolutions, the methods and means available for the rehabilitation of these patients have varied in a considerable manner, with a greater importance allocated to technological devices [7]. This evolution was made possible by the advances in neurosciences that enabled the better understanding of brain plasticity mechanisms underlying the phenomena of sensorimotor and cognitive recovery [8,9] as well as the better integration of learning theories in our rehabilitation programs. These progresses have completely altered the principles driving our rehabilitation practices [10] with the emergence of new ideas such as the notion of task-oriented rehabilitation training, the new focus on the importance of intensity and repetition of exercises, as well as challenging the commonly admitted duration of our rehabilitation programs. This evolution has been widely influenced by the emergence of new technologies that found in this pathology an increasingly larger field of potential applications. Finally, this evolution of concepts and practices was associated to important progresses in rehabilitation-related professions and the healthcare organizations managing these patients.

The objective of this work was to propose a non-exhaustive synthesis of the main technologies involved in the rehabilitation of hemiplegic patients based on a review of the literature conducted on ''Medline'' and ''Web of Science'' for the period going from 1990 to 2013.

1.2. Rehabilitation technological devices

1.2.1. Neuromuscular or functional electrical stimulation (FES)

Motor-stimulating currents were proposed more than 30 years ago for the rehabilitation of hemiplegic patients. The simple use of these currents was quickly enriched by more elaborated functions such as devices coupling detection and stimulation to let the patient's own motor functions express themselves during a voluntary task (Fig. 1), before motor-stimulating currents take over [11]. This technique has showed its effectiveness for the upper limbs, especially in hemiparetic patients [12]. These devices can easily be integrated into ''task-oriented'' rehabilitation programs; in fact electrical stimulation is dedicated to the patient's movements rendering them possible and easier to complete (FES). Thus, FES can be used for gait (e.g. Walkaid® system) or grasping (e.g. Handmaster® system) tasks. It is interesting to note that these particular devices, initially designed for orthotic purposes, seem to have a therapeutic relevance by improving the motor functions in the stimulated muscles [13].

1.2.2. Rehabilitation robotics

Rehabilitation robots are interactive motorized devices allowing the mobilization of a limb for sensorimotor rehabilitation but also potentially, for cognitive rehabilitation. Rehabilitation robotics, whether they concern the upper or lower limbs, are generally divided into two categories: automated exoskeleton that move the limbs by controlling the displacement of each segment, and devices that enable the mobilization of a limb from a distal application point (Fig. 2), without the control of the various joints [14]. Depending on their design, these robots work in two or three dimensions. They are designed with different working modes: simple passive mobilization, robot-assisted mobilization that interacts more or less with the subject, and resistance training. Most robots enable the interaction with a virtual environment. The technological sophistication of these different systems is quite uneven, reflecting the yet not completely mature nature of these technologies [15].

The oldest rehabilitation robots are in fact isokinetic dynamometers; they are dedicated to instrumental muscle strength training and completely fit the definition of rehabilitation robotics. In hemiplegic patients, their relevance in lower limb

Fig. 1. Functional electric stimulation of the upper arm during an occupational therapy session.