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From the past to the future of therapeutic orthoses for upper limbs rehabilitation

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Abstract **Introduction:** The expansion of assistive technologies has been increasing significantly, involving almost all the daily activities, performed by disabled people. One of the highlights to be mentioned is the robotic orthoses, which are being used to amplify movements, to replace amputated limbs, and for a variety of rehabilitation therapies, among others. This study aims to present a review about upper limbs' orthoses, discussing their weaknesses, potentialities, and pointing out for future perspectives under the motor rehabilitation. **Methods:** For this research, it had been identified 161 papers, based on the bibliographic bases from IEEE and Science Direct, which were filtered by the keywords orthoses, hand, upper-limbs and technology. After the appropriate exclusions, 22 papers were analyzed. **Results:** This review indicates that most of the orthoses have been developed for rehabilitation therapies to be employed by people who have suffered stroke, cerebral palsy or spinal cord injury. This research summarized that the upper limbs movements are effectively produced by electric or pneumatic actuators, having a variety of degrees of freedom. **Conclusion:** This review has shown that, although there are many orthoses styles, ranging from electric to pneumatic actuators; also there are some technical restrictions that prevent their use by most people. However, upper limb orthoses seem to be a great solution for the rehabilitation of people who have suffered a stroke.

Keywords Orthosis, Upper-limbs, Functional rehabilitation, Therapeutic device.

Introduction

The human hand is an extremely sophisticated instrument used to perform almost all activities of daily living, such as for picking up objects, typing, writing, among many others (Aubin et al., 2013). For most people, these activities are trivial. However, for certain groups of people, those tasks are somehow very complex or even impossible. The paralysis represents a loss of the muscle function caused by damage to the nervous system. Some common causes of upper limbs paralysis are stroke, traumatisms, spinal cord injuries, multiple sclerosis or cerebral palsy (Meng et al., 2015), in which a simple act of holding an object is considered as a major obstacle. When the paralysis occurs affecting only one side of the body, it is known as hemiplegia (Ates et al., 2013).

Stroke is the leading cause of adult disability and the second or third cause of death in developing countries, resulting in a loss of the brain function due to a disturbance in the blood supply (Bae et al., 2012). According to the latest national health survey conducted by the Brazilian statistics government center (IBGE), in 2013, there were 2.2 million people diagnosed with stroke injuries in Brazil (Instituto..., 2013). Moreover, in the United States of America, after each year, there have been about 795,000 people with stroke (Gasser and Goldfarb, 2015), of which 22% die within the first 30 days. Around 80% of them are in need for rehabilitation therapies (Meng et al., 2015), and only between 5% and 20% can fully recover their motor control (Nijenhuis et al., 2015). Additionally, stroke is known as the third major cause of death in the U.S.A. (Patar et al., 2014).

During conventional stroke therapies, the assistance is provided by the physiotherapists, but the training exercises that must be carried out at home can be boring and demotivating. In this sense, rehabilitation robots are useful tools to treat post-stroke impairments, which are considered as a complement to conventional therapy (Ates et al., 2013). It is known that interventions involving highly repetitive, task-specific training in a motivating environment with active contribution of the patient are

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important for optimal motor relearning (Nijenhuis et al., 2015; Ochoa et al., 2011).

Exoskeletons and orthoses for rehabilitation process has grown gradually (Aubin et al., 2013; Bae et al., 2012). They differ each other based on the types of the actuators which are responsible for the movements to be performed, and usually are pneumatic, hydraulic or electric (i.e. by motors) (Gopura et al., 2016). Currently, this research corresponds to an area in great expansion, and the increasing of the motor skills in hands and wrists allowed significant improvement in the lives of people who need assistance within such movements (Ates et al., 2015; Housman et al., 2007; Nijenhuis et al., 2015; Patar et al., 2014).

Orthoses allow the patient to do some hand movements, even without the need for local assistance of a therapist. These devices enhance improvements reducing rehabilitation time. Additionally, it provides quantitative feedback, data collection, and analysis in real time (Aubin et al., 2013; Housman et al., 2007; Ochoa et al., 2011).

Rehabilitative therapies that can be performed at home have the potential to augment standard care and have the advantages of being more convenient, less expensive, and provide greater training frequency and intensity when compared to the conventional care delivered one-on-one by a therapist in a clinic. Robotic rehabilitation devices can be programmed to provide movements and torques to specific joints in a repetitive manner, while quantitatively they allow to monitor the progress over timescales that ranges from seconds to months (Aubin et al., 2013).

However, most of the current orthoses employed at home are the passive type, without active components for helping the movement of the extremities. According to Housman et al. (2007), many of these home orthoses have fewer degrees of freedom, limiting the mobility of the user. Also, some devices are difficult to adjust, and they provide a low facility in changing the supports to alter the movement levels and provide very little or no feedback at all for the recovery of the movements.

Despite of increasing statistical data on people with motor disabilities and the relevant scenario of developing rehabilitative technologies, the literature focuses exclusively on functional assistive devices. Then, it was not found current reviews about therapeutic orthoses. For this reason, it was conducted a systematic survey, ranging about the specificities of designs for upper limbs' rehabilitation orthoses, built especially for hands. For this purpose, we have looked for identifying the technologies described in the literature, as well as for showing their structure, functionality, types of movements performed and therapeutic applications. So, the main purpose of this paper is to present the state of the art on the orthoses' design for upper limbs, discuss their weaknesses and capabilities and to point out future perspectives, under the therapeutic rehabilitation point of view.

Method

The *IEEE Xplorer* and *Science Direct* research platforms were used to get access to the papers, performing an advanced search based on the following keywords (only in English language): orthosis, hand, upper-limbs, technology. The search for the papers was narrowed ranging over the last ten years window period. Also, it was considered all the papers that had in their abstract the surveyed keywords. Figure 1 shows the flowchart used to illustrate how this search was performed.

On the *IEEE Xplorer* database, at the advanced search option, the keywords are uploaded, specifying 10 years, allowing the options search for full text and

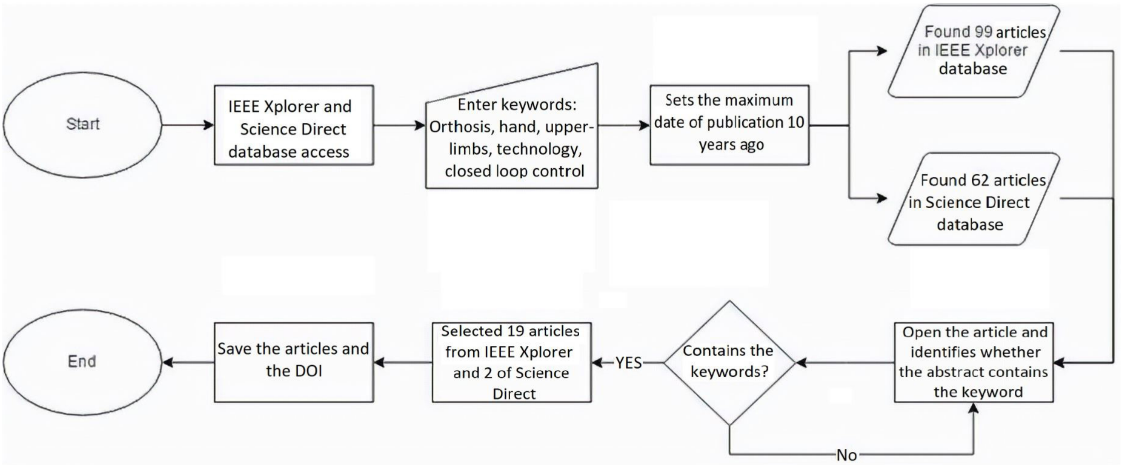


Figure 1. Flowchart for the literature search strategy.

metadata. Also, it was filtered only papers published in conferences.

At the *Science Direct* database, for the advanced search, it was necessary to specify the keywords with a Boolean search AND. Also, it was specified for 10 years, and it was narrowed selecting only engineering projects, excluding medical and other papers. The reason for this window period is due to the rapid technology changing, focusing on the search of non-obsolete solutions. And the engineering approach is justified towards the emphasis on the development of orthoses, including studies within hardware and software solutions.

After collecting all the papers found on both database, there was a narrow search by checking the abstracts of each paper, looking for the existence of the keywords used at the main search descriptors. From the articles selected, it was extracted information regarding the applied segment, degree of freedom, the method of actuation, the application, the method of power transmission, the connection setup, and the controlling system.

Results

According to Gopura et al. (2016), the orthoses for upper limbs can be classified based on their anatomical fitting, degrees of freedom, actuator's methods, configuration, controlling method or depending on the application. Table 1 presents a summary of the classification that is described in the literature.

Most of the papers describe good details of the orthoses since they bring information about classification, actuator's types, degrees of freedom and applications. Table 2 synthesizes all this information, gathering by the type (arm, wrist, and hand), the actuators (pneumatic, electric or manual), and its application regarding the rehabilitation therapies.

Table 1. Orthoses classification of the upper limbs (Gopura et al., 2016).

Applied segment	Hand and forearm orthoses, full upper-limbs or with combined segments
Degree of freedom	Independent parameters that define the configuration or degrees of freedom (DOF): 1DOF, 2DOF 3DOF, and so on.
Method of actuation	Electrical, pneumatic, hydraulic or combination of two or more types (hybrids)
Application	Robotic rehabilitation, human amplification, assisted technologies, tactile interfaces, among other applications.
Method of power transmission	Gear drive, cable drive, a linkage mechanism, belt drive, ball screw drive, a combination of two or more methods (hybrid)
Connection setup	Serial, parallel or hybrid
Controlling method	Control by impedance, by force, neuro-fuzzy, among other methods.

Table 2. Information found about orthoses in the selected articles.

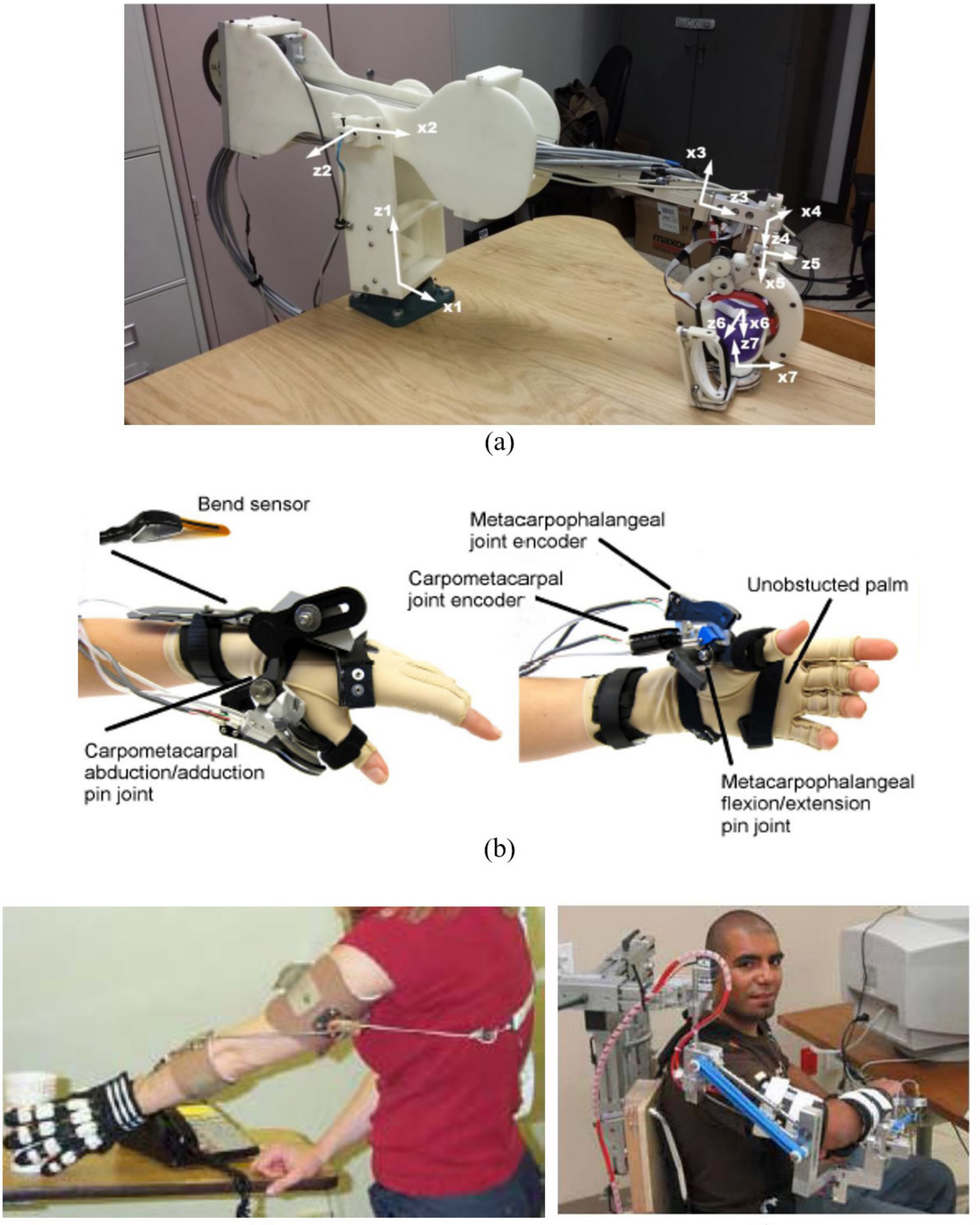
Author	Type	Actuator	Degrees of freedom	Type of movement	Application (rehabilitation therapy)
Holley et al. (2014)	Wrist	Electric	2	Extension and flexion, pronation and supination of the wrist	Children with cerebral palsy
Aubin et al. (2013)	Wrist	Electric	2	Extension and flexion of the wrist and thumb	Children with cerebral palsy
Luo et al. (2005)	Hands and fingers	Cable	Not specific	Not specificm	People who suffered a stroke
Housman et al. (2007)	Arm	Manual	5	Not specific	People who suffered a stroke
Ates et al. (2015)	Wrist, Hands, and fingers	Electric	3	Extension and flexion of the fingers, adduction, and abduction of the thumb and extension and flexion wrist	People who suffered a stroke
Wolbrecht et al. (2006)	Arm	Pneumatic	4	Forward/backward clavicle rotation, shoulder flexion/extension, shoulder horizontal abduction/adduction, and elbow flexion/extension.	People who suffered a stroke
Low et al. (2015)	Fingers	Pneumatic	2	Extension and flexion	Not informed
Meng et al. (2015)	Wrist	Pneumatic	1	Extension and flexion	People who suffered a stroke

Table 2. Continued...

Author	Type	Actuator	Degrees of freedom	Type of movement	Application (rehabilitation therapy)
Koo et al. (2009)	Arm	Electric	2	Elbow and wrist extension	Active and passive assistance for the patient himself to move his arms
Gasser and Goldfarb (2015)	Hands and fingers	Electric	1	Extension and flexion	People who suffered a stroke
Oboe et al. (2010)	Hands and fingers	Electric	1	Extension and flexion	People who suffered a stroke
Gopura et al. (2016)	Upper limbs	Manual	N/A	N/A	N/A
Nijenhuis et al. (2015)	Wrist and hand	Manual	3	Extension and flexion of the fingers, adduction, and abduction of the thumb and extension and flexion of the wrist	People who suffered a stroke
Martínez-Valdés et al. (2014)	Hands and fingers	Electric	1	Extension and flexion	People who suffered a neuromuscular lesion
Leeb et al. (2010)	Hands and fingers	Electric	1	Extension and flexion	People who suffered a stroke
Ates et al. (2013)	Hand and fingers	Manual	3	Extension and flexion of the fingers, adduction, and abduction of the thumb and extension and flexion of the wrist	People who suffered a stroke
Ragonesi et al. (2011)	Elbow and arm	Electric	4	Extension and flexion of the shoulder and elbow	People who suffered a stroke
Patar et al. (2014)	Hand and fingers	Pneumatic	1	Extension and flexion	People who suffered a stroke
Ates et al. (2014)	Hand and fingers	Manual	3	Extension and flexion of the fingers, adduction, and abduction of the thumb and extension and flexion of the wrist	People who suffered a stroke
Ochoa et al. (2011)	Hand and fingers	Electric	1	Extension and flexion	People who suffered a stroke
Bae et al. (2012)	Wrist and hand	Pneumatic	3	Extension and flexion of the fingers, adduction, and abduction of the thumb and extension and flexion of the wrist	People who suffered a stroke

Holley et al. (2014) developed upper extremity orthoses composed of a 3 DOF arm and 4 DOF wrist, built with actuators having 2 degrees of freedom. The structure is mounted on a table and is designed for applications in the therapy of children with cerebral palsy. For the achievement of the movements of the wrist, it is employed a brushless motor, operating in DC mode. It generates a 5 Nm continuous torque at the wrist, thus creating movements of extension, flexion, pronation and supine. The control is done through a computer algorithm, transmitted via Ethernet cable. Figure 2a illustrates the orthosis, representing all the motion axes (x, y, and z-axis). Aubin et al. (2013) developed a wrist orthosis for daily use. This device has 2 DOF and its use is intended for children with cerebral palsy. The orthoses enable flexion and extension of the articulated components connected to it. The mechanical structure was mounted on a glove made of Lycra, and all movements are performed based on a servo motor. This device is mounted on a stable aluminum platform. Figure 2b displays the compacted device that controls the orthosis based on an Arduino Mega 2560, being fed with batteries. Luo et al. (2005) described a computational system that integrates an interface with virtual reality goggles, manual orthoses, and a computer game, as shown in Figure 2c. Through the virtual reality goggles, the user is immersed in the game scene, with the purpose to hold an object. The orthosis is used when the person presents difficulties during the extension of the fingers. Then, based on a sensor, the therapist (who could be close to the user or watching him via a webcam) can check if the fingers are extended enough, allowing the therapy process. If necessary, the user increases the extension of all the fingers together.

Housman et al. (2007) proposed the construction of an orthosis for arm holding, called Therapy Wilmington Robotic Exoskeleton (T-WREX), which is based on a similar orthosis - Wilmington Robotic Exoskeleton (WREX) created by Dr. Tariq Rahman. The T-WREX orthosis was designed to be a low-cost, passive training



(a)

(b)

(c) (d)

Figure 2. Literature's review examples: (a) The z-axes represent the axis of rotation, while translation from one joint to the next occurs along either the x or z-axis (Holley et al., 2014); (b) moving points and components of the orthosis (Aubin et al., 2013); (c) orthosis connected being worn by a user; a zipper is sewn into the palmar side of the glove facilitates fitting (Luo et al., 2005); and in (d) the orthosis provides gradable support for the arm against gravity using elastic bands, and measures arm movement and hand grasp as the user interacts with computer simulations of functional activities (Housman et al., 2007).

device, easily adjustable, that provides a variety of support in a large 3D workspace and quantitative feedback, and it allows a semi-autonomous arm training. Figure 2d illustrates the device being used by a volunteer.

Ates et al. (2015) suggested improvements at the SaeboFlex orthosis, calling it the SCRIPT Active Orthosis Iteration 3 (SAO-i3), which performs movements of flexion and extension of the fingers, produced by a low-cost DC motor. Since the motor performs such movements, it drives a cable through a pulley that moves all the fingers together. The motor control is carried out by a microprocessor - Arduino MEGA 2560, based on the communication with a computer. Figure 3a shows the orthosis placed on a hand. Wolbrecht et al. (2006) also used the same concept of the orthosis Wilmington Robotic Exoskeleton (WREX), created by Dr. Tariq Rahman. For this variation, it was developed a pneumatic arm orthosis with 4 degrees of freedom, called Pneu-WREX. Figure 3b illustrates one of the degrees of freedom achieved by this orthosis. Low et al. (2015), developed a pneumatic finger orthosis embedded with actuators on each phalanx (Figure 3c). For safety, it employed wireless electromyographic electrodes, from Trigno (Delsys Inc., Boston, MA), to monitor muscle activity. This functionality provides support for movements of flexion and extension of the orthosis, but only when there is muscle contraction. Meng et al. (2015) used two pneumatic muscles (Festo Fluidic Muscles DMSP20) called PAM (*Pneumatic Artificial Muscles*). In this case, the wrist movements of flexion and extension are held based on pneumatic cylinders, which are moved back and forth. Therefore, it is represented as moving a thread by a cylindrical hinge, as shown in Figure 3d. The motion angle control is performed by a potentiometric sensor, which is connected in the middle of the joint. Figure 3e illustrates the 3D concept showing that when the PAM 1 and PAM 2 are pressurized occur the movement of the wrist extension and when unpressurized occur the movement of the wrist flexion.

Koo et al. (2009) proposed the development of an orthosis of neutral gravity, where bi-directional sensors, placed on the hand, can identify the flexion and extension movement of the wrist. So, this signal is processed via Matlab, and it is transmitted to a stepper motor that controls a pulley, aiding the flexion and extension movement of the arm. Figure 4a illustrates the application of this orthosis with a volunteer. Gasser and Goldfarb (2015) have developed a prototype of a hand's orthosis that performs flexion and extension movements of the fingers altogether, only excluding the thumb, as shown in Figure 4b. The movements' control is done by two brushless DC motors inside the orthosis. The main structure of the device is comprised of a high modulus thermoplastic resin. Oboe et al. (2010) developed an orthosis divided into two pieces: a master and a slave device. The slave device consists of a stainless-steel plate fixed on the forearm. The device also carries an elastic actuator, which consists of springs connected in series, between the engines and the output of the actuator. The mechanism to move the fingers, for controlling the electronics and the power supply, is shown in Figure 4c. The master device was built to provide a realistic feeling when the therapist handles. This device is controlled via personal computer, based on Matlab/Simulink, using a Sensoray 626 data acquisition board. Nijenhuis et al. (2015) and Ates et al. (2013, 2014) employed the same hand orthosis on a project called *European SCRIPT*. The movements of the orthoses are produced from the voluntary muscle activation, which is the flexion and extension of the wrist, hand, and fingers. Figure 4d shows these extension and flexion movements of the wrist.

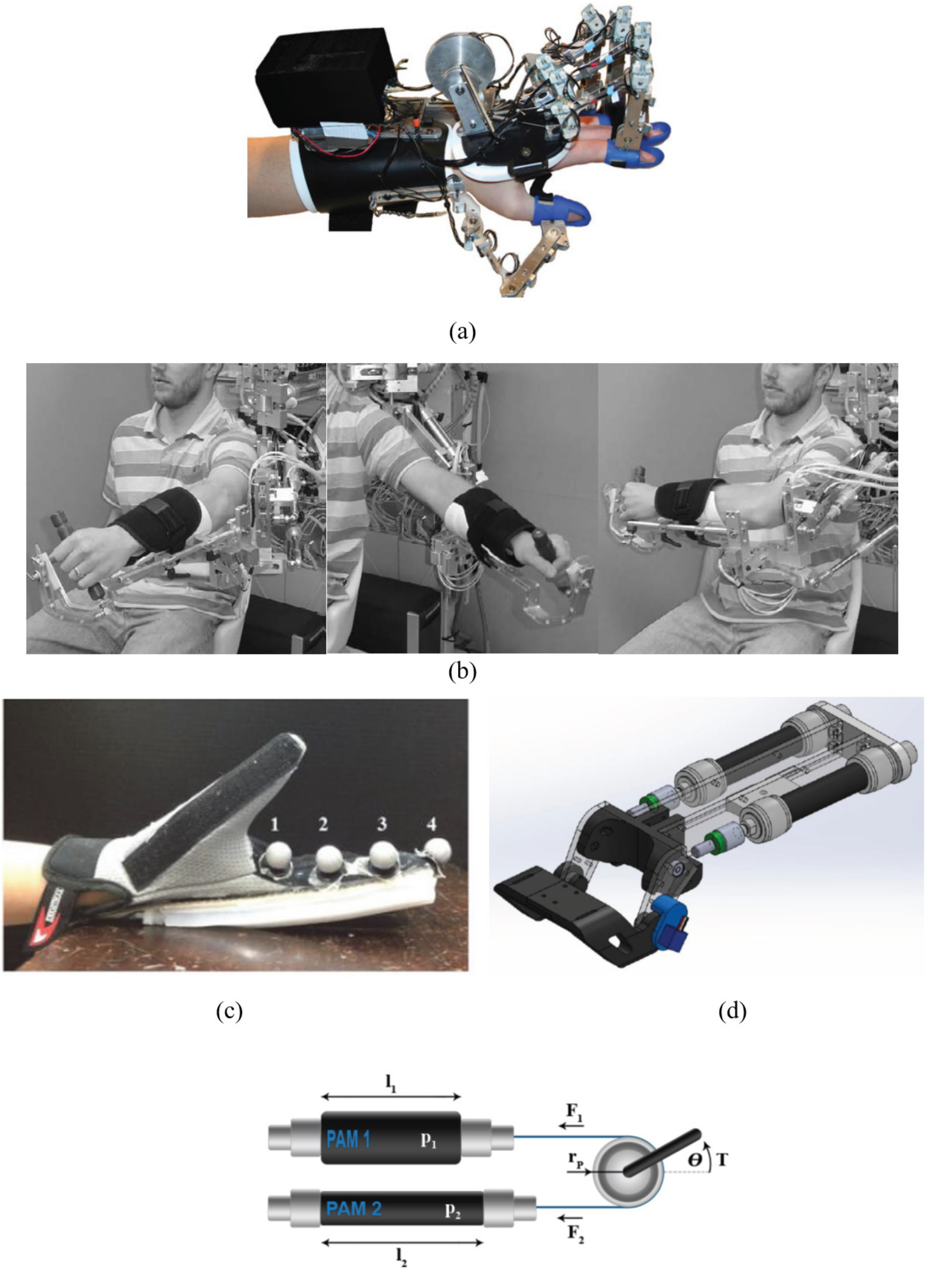
Flexion and extension movements of the wrist are achieved by the use of a dual mechanism, which carries out the movement of wrist and hand together. It also contains a sensor to measure the bending angle, for flexion and extension. The finger mechanism consists of a combination of springs, elastic cords, and an angle sensor. There are also knots in the elastic cords, which allows the user to adjust manually the initial voltage and the total force applied to the finger. The orthosis' components are detailed below, and it is shown in Figure 5a:

- fingers mechanisms: a set of springs and adjustable elastic cords;
- wrist mechanisms: double parallelogram between hand and forearm;
- driver/controller's device: microcontroller card enabling for sensor readings and conversions (not shown);
- State sensors: an inertial measurement unit (IMU) for estimation of the initial integrated forearm positions.

Martínez-Valdés et al. (2014) have prepared the design for building a hand's orthosis, allowing for flexion and extension movements of the fingers. The main purpose of this project is to build orthoses weighing less than 0.5 kg. Figure 5b shows a prototype of such orthosis for the fingers, especially showing the stress probe for fixation and joints. Leeb et al. (2010) report the use of neuromuscular electrical stimulation, which allows movement of the hand in people with spinal cord injuries. Figure 5c shows a child wearing this device, having the shoulder and arm flexed.

Ragonesi et al. (2011) carried out a research where the goals of the project are to measure the user's force and to apply the appropriate actuation. This is due to assist the user's movement easily, either with or without a weight at the hand. They employed the device

Wilmington Robotic Exoskeleton (WREX), created by Dr. Tariq Rahman, aiming to eliminate the action of the arms gravity's force, thus allowing better handling of the limb. This shoulder and arm orthosis have four DOF, two designed for the shoulder and two for the arm. A brushed DC motor performs the movements, since the movements are based on the communication with a computer that simulates the movements.



(a)

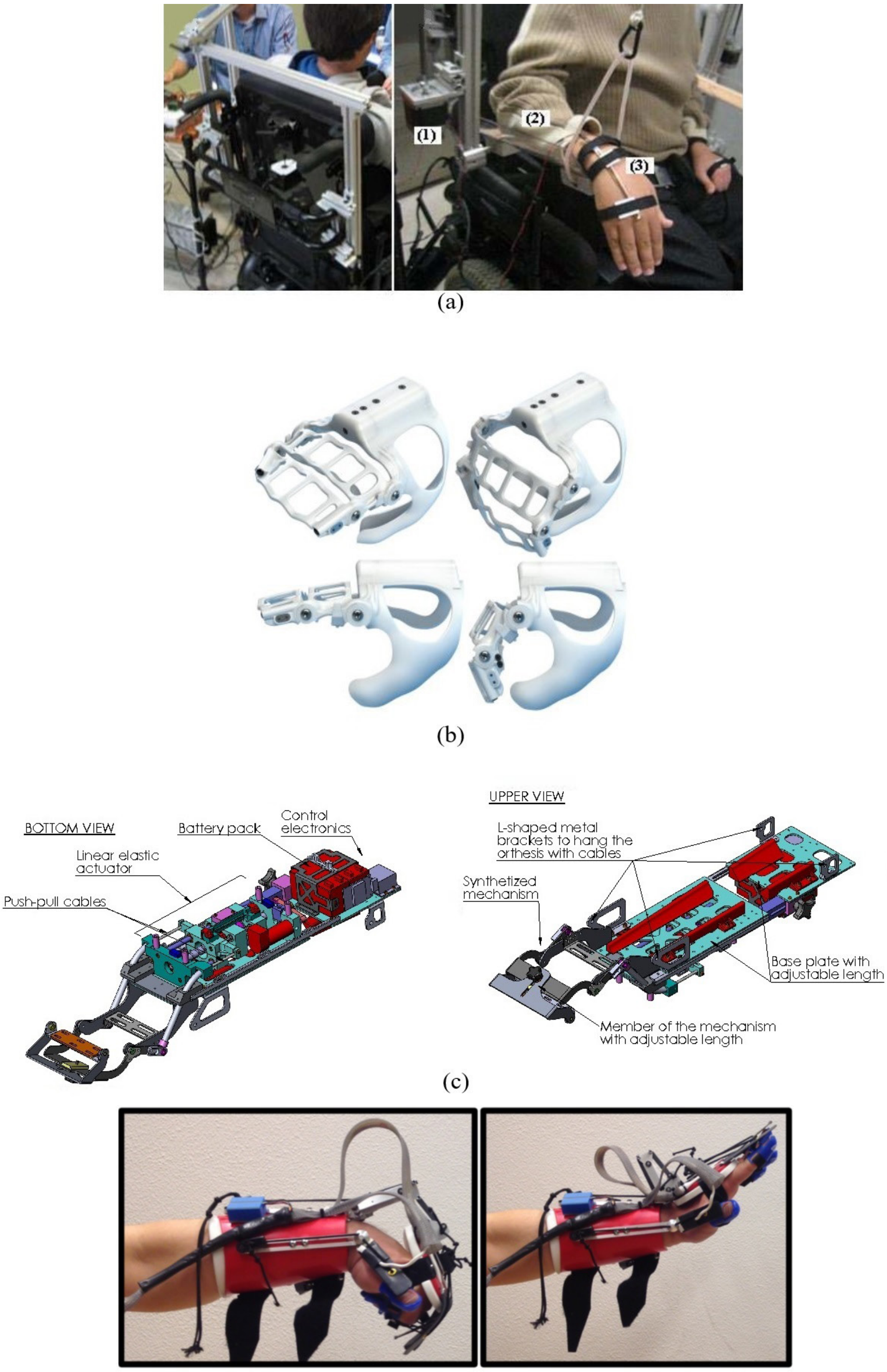
(b)

(c) (d)

(e)

Figure 3. System's examples: (a) complete structure device of the orthosis by Ates et al. (2015) mounted on the hand; (b) Pneu-WREX orthosis: this device has four degrees of freedom (DOF) corresponding to the forward/backward clavicle rotation, shoulder's flexion/extension, shoulder's horizontal abduction/adduction, and elbow flexion/extension; allowing a nearly full range of natural human arm motions (Wolbrecht et al., 2006); (c) for the movement of the metacarpophalangeal joint, at the segments 1-2 it has applied a pressure of 1 bar, performing the flexion angle. For the proximal interphalangeal joint, it is applied pressure at the segments 1-2 and 2-3. Moreover, for the flexion angle at the distal interphalangeal joint, it is applied pressure at the segments 2-3 and 3-4 (Low et al., 2015); (d) Mechanical design of the wrist orthosis (Meng et al., 2015); and (e) Force's distribution on the orthosis (Meng et al., 2015), where: P_1 and P_2 represents the pressures on the fluidic muscles; F_1 and F_2 corresponds to forces on the pulley; l_1 and l_2 represents fluidic muscles length; r_p means radius of the pulley; T is the resultant Torque; and $\boldsymbol{\theta}$ represents the hand's angular displacement).

The orthosis may push and pull flexible strips to perform the movements of flexion and extension, keeping these cops on the hand, allowing a free palm with thumb stabilized, and avoiding muscle fatigue caused by electrical stimulation (Figure 6a), as shown in Figure 6b and Figure 6c. Flexible strips are fixed in



(a)

(b)

(c)

(d)

Figure 4. Examples of orthoses: (a) device properly mounted on the user's under a wheelchair (aa); and user (ab) with gravity neutral orthosis (GNO), showing the motor (1), the arm shelf (2), and the flexion of the hand and its sensor bounded in it (3) (Meng et al., 2015); (b) Orthoses' prototype by Gasser and Goldfarb (2015), showing the movements of all the fingers; (c) Top and bottom views of the orthosis (Oboe et al., 2010); (d) Pictures indicating the maximum flexion point (left) and extension point (right) of the wrist and fingers (Nijenhuis et al. (2015) and Ates et al. (2013, 2014)).

each finger, as represented in Figure 6b, where they are firmly tightened around the middle of each fingertip by adaptable leather belts.

Patar et al. (2014) proposed a pneumatic hand's orthosis for the movement of the thumb, the forefinger, and the middle finger, as shown in Figure 7a. This device

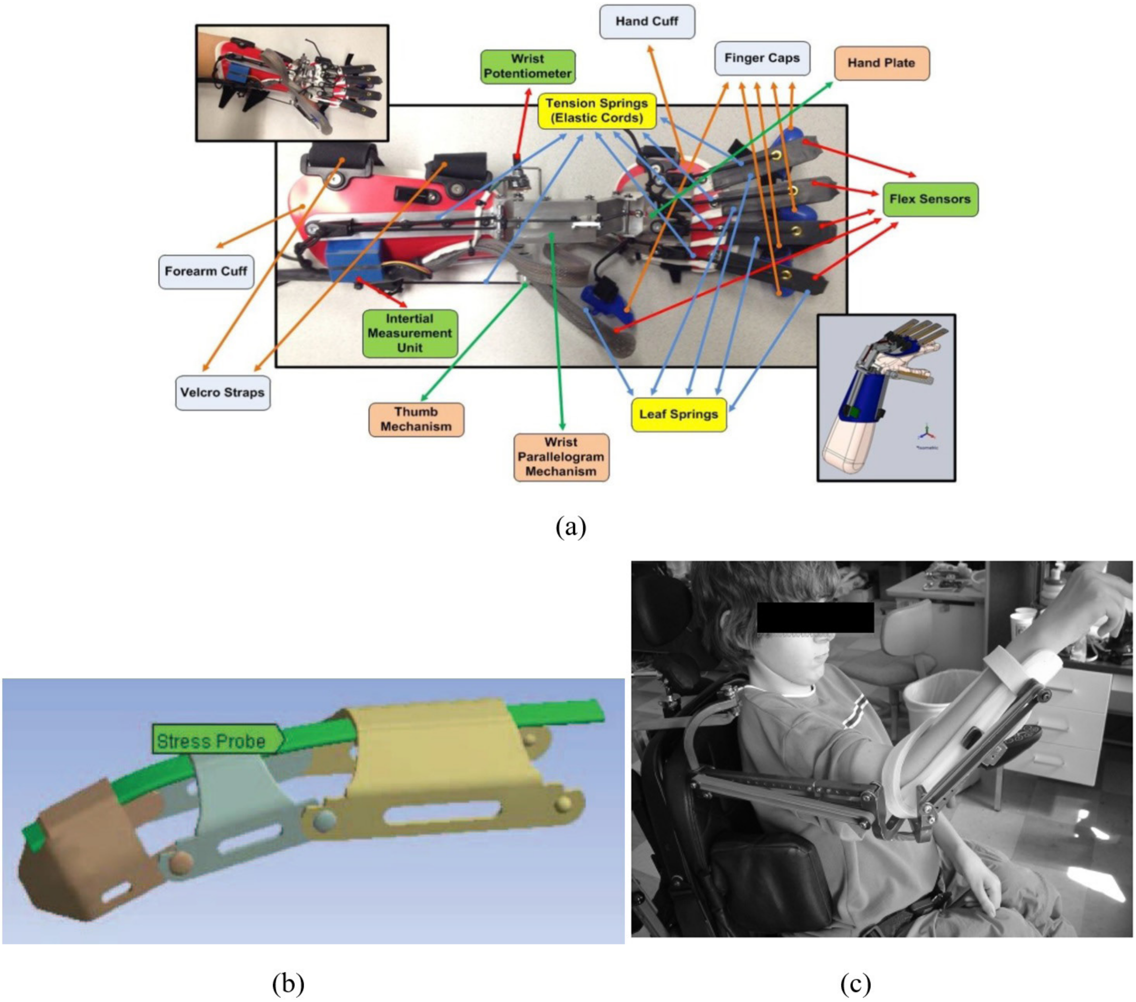


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Figure 5. (a) The hand's orthoses and its major components (Nijenhuis et al. (2015) and Ates et al. (2013, 2014)); (b) simulation of the tendon movement, including the way of fixation in the joints (Martínez-Valdés et al., 2014); (c) the controlling method was tested in Simulink, as well as in the experiment, using Matlab within a computer (Ragonesi et al., 2011).

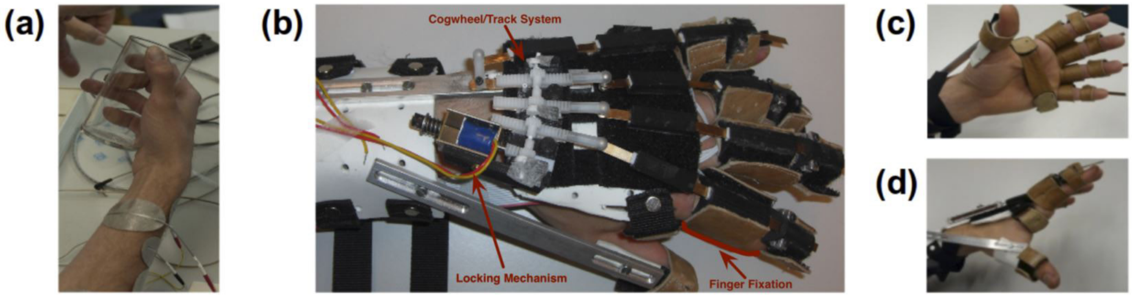
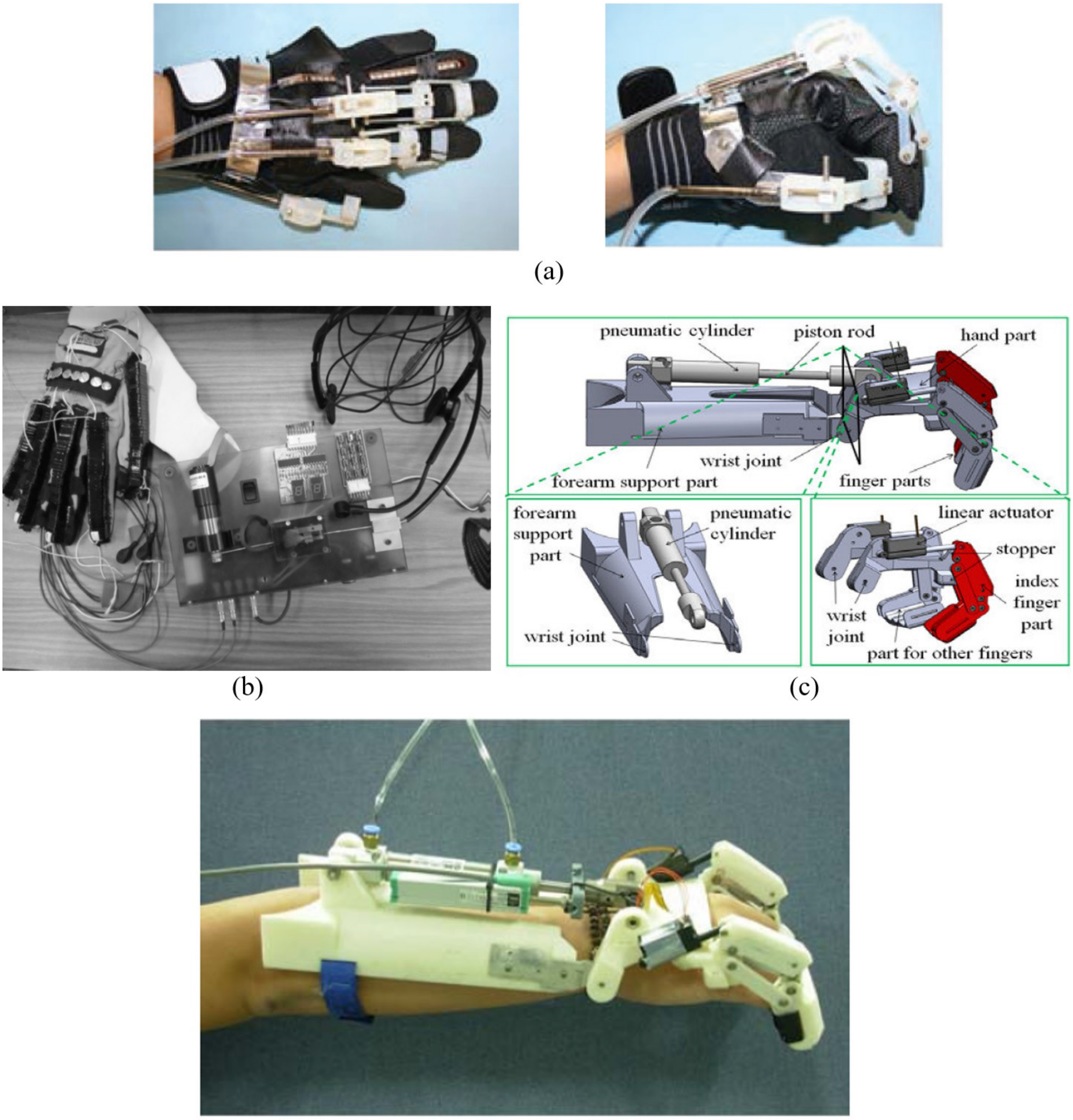


Figure 6. (a) The hand with muscular electrical stimulation, indicating that the middle finger provides the strongest force (white fingertip due to lower blood perfusion), while the ring finger has no force contribution; (b) Orthoses mounted on the backhand and the distal forearm. Sheaths are attached with Velcro to guide the tendon-like bendable strips from the finger to the synchronization mechanism on the back of the hand; (c) Representation of the palm and the fingertips, which are remaining free; (d) The thumb being stabilized (Leeb et al., 2010).



(a)

(b)

(c)

(d)

Figure 7. (a) Patar's orthosis has been tested on a healthy individual to perform the flexion movement (left) and the extension movement (right) (Patar et al., 2014); (b) The Bowden cable connects to a servo motor, which drives the glove. All these electronics are only located in this single box (Ochoa et al., 2011); (c) The 3D layout of the orthosis, detailing each component (Bae et al. 2012); (d) The layout of the orthosis fixed on the forearm, wrist, and hand (Bae et al., 2012).

uses a small pneumatic cylinder to perform movements of flexion and extension. The orthosis is controlled by a computerized system, which was implemented in C^{++}, since it triggers the pneumatic system. Ochoa et al. (2011) developed a hand's orthosis, where cables and a servo motor were controlled by pulse width modulation (PWM) through a microprocessor, the Rabbit (RCM 4510, by Digi International Inc., Davis, CA, USA), as illustrated in Figure 7b. Bae et al. (2012) designed a wrist and hand's orthosis called DULEX-II as represented in Figure 7c. It is based on a pneumatic cylinder for the movements of the wrist handle and two engines for the movement of the fingers. The pneumatic cylinder is fixed on the forearm, where it mimics the flexion and extension movements of the wrist, as shown in Figure 7d.

Discussion

Considering the literature review presented herein, it is possible to suggest that the research for most functional orthoses consists of two main characteristics: (1) low-weight (Ates et al., 2013, 2015; Aubin et al., 2013;

Gasser and Goldfarb, 2015; Leeb et al., 2010; Low et al., 2015; Martínez-Valdés et al., 2014; Wolbrecht et al., 2006), and (2) the type of the actuator employed; in which the pneumatic actuator is considered as the better proposed solution (Bae et al., 2012; Low et al., 2015; Meng et al., 2015; Patar et al., 2014; Wolbrecht et al., 2006). These two features are the major issues for using within rehabilitation therapies. However, compared to the electric actuators, its structure tends to be bigger than the other types, considering the use of pneumatic cylinders and compressors. Therefore, this last characteristic compromises the use of these orthoses in-house environments.

Holley et al. (2014) and Aubin et al. (2013) developed wrist and hand orthoses for rehabilitation therapies in children with palsy. In Holley et al. (2014) (Figure 2a), the device needs to be sustained on a table for the achievement of the movements, although having the control performed by a computer. Therefore, it requires the full assistance of a therapist to accomplish the movements. On the other hand, Aubin et al. (2013) developed their orthosis using a glove, in which the movements are controlled by an interface (Figure 2b), becoming simple and compact. Regarding the difference in the amount of degrees of freedom between these orthoses, Holley et al. (2014) presented a more realistic orthosis compared to the other, having natural movements, involving extension and flexion, pronation/supination of the wrist, while in the Aubin et al. (2013) orthosis, there is only the flexion and extension movements.

Oboe et al. (2010) developed an orthosis which enables to evoke only the flexion and extension movements of the fingers (Figure 4c). The movement is based on cables linked to engines, and it contains all its structure on the forearms. This orthosis has no wires and can be remotely controlled, performing only the finger movements. The orthosis by Bae et al. (2012) (Figure 7d) use a pneumatic cylinder for the wrist movement and it couples with an air compressor, which is needed to allow the movement of the pistons. Since this configuration prevents movement, it has a mechanism that can move the fingers together based on the movement of the DC motors. Regarding DOF, it performs the extension and flexion movements of the wrist and the fingers.

Nijenhuis et al. (2015) and Ates et al. (2013, 2014) employed the same orthosis, named SCRIPT Active Orthosis Iteration 3 (SAO-i3) (Figures 4d and 5a). This represents a complete kind of orthosis, which can perform wrist, hand and fingers movements. In this way, it offers safety to the user, since it does not employ pneumatic or electric systems. The limitation of the movements performed by the user becomes a serious constraint that could be overcame by adding electrical and electronic components. However, as Nijenhuis et al. (2015) reports, it is necessary to ensure that the weight of the orthosis does not cause discomfort to the user; otherwise rather than generating improvements, it could produce difficulties for the adaptation at the proposed therapy. Therefore, Gasser and Goldfarb (2015) and Ates et al. (2015) developed a prototype of a hand's orthosis, which is able to produce the movements of all the fingers at the same time. The orthosis design of Gasser and Goldfarb (2015) (Figure 4b) carried out the benefits of a brushless DC motor located inside the orthosis, saving space; and, therefore, decreasing the structure's size. The Ates et al. (2015) orthosis (Figure 3a) has a motor and a pulley for the movement of the fingers, representing a restriction of this configuration for daily use. The Gasser and Goldfarb (2015) device has only one DOF. On the other hand, the Ates et al. (2015) orthosis has four DOF, which is different from each other, regarding automation. However, with technological advances, the use of servo motors on this SCRIPT orthosis would facilitate its automation.

Housman et al. (2007) (Figure 2d) and Ragonesi et al. (2011) (Figure 5d) used orthoses for shoulder and elbow movements, coupled within a chair, but discarding the wrist and hand movements. Extension and flexion movements of Ragonesi et al. (2011) orthosis are performed based on a DC motor controlled by a computer system. The Housman et al. (2007) orthosis allows that all movements are performed manually. Since they allow a larger number of DOF, they become big and complex structures, discarding their homely use. On the other hand, Gasser and Goldfarb (2015) have developed a lightweight and adjustable structure for hands' orthosis. The movements are performed by two motors, allowing the hand's palms to become free. It enables to be used in therapies consisting of holding objects. However, it immobilizes the thumb, having the movements of the other fingers altogether. Therefore, it does not allow localized therapy for only either one finger or another.

Leeb et al. (2010) and Ochoa et al. (2011) also developed orthoses with the connected movement of the fingers using servo motors, although not discarding the movement of the thumb. Leeb et al. (2010) (Figure 5c) used this orthosis to prevent muscle fatigue caused by the use of electrical stimulation for moving the fingers. Furthermore, Martínez-Valdés et al. (2014) (Figure 5b) had focused on calculating the force required for the movement of the fingers, using a structure built on a 3D printer. On the edge of the structure, a blade is attached that is pulled or pushed, performing the flexion and extension movements. The main advantage of this orthosis is its weight, which is less than 0.5 kg. However, its use is limited to people who do not have spasticity, due to its fragile structure. Most of the studies reported here describe projects involving orthoses for adults who have suffered from cerebrovascular accident (stroke) and children with palsy.

Remarkable approaches for the development of upper extremities orthoses

From data presented herein, some criteria are mandatory for the development of an upper limbs orthosis. Firstly, it is necessary to define its application (robotic rehabilitation, human strength amplification, assisted therapy, among others); because this defines the main parameters to be considered, which are: DOF, actuators type, method and strategy of movements control.

The degrees of freedom can be defined by the goal of the orthoses, which is paramount for the choice of the actuators. The articles selected for this review show that 47% use DC electric motors, 23% uses pneumatic actuators and 28% manual ones. Therefore, DC electric motors represent a tendency for application within orthotics, mainly due to its easy configuration and control, which together with gear systems, can provide higher torques. An interesting alternative is the application of hybrid components, such as the orthosis developed by Bae et al. (2012), which uses pneumatic cylinders for wrist movement and DC electric motors for finger movements. Artificial muscles can be a promising alternative to replace the standard actuators already in use, with the advantages of its small size with the possibility for exclusion of motors or pneumatic cylinders. However, nowadays, the high heat generation is considered their limitation.

To achieve the proper torque, besides the type of actuator, the overall weight of the orthosis that depends on the construction material must be well-defined. Also, the material must have the mechanical resistance and flexibility necessary to provide the functionality and the safety expected. With the advent of 3D printing, the polymer acrylonitrile-butadiene-styrene (ABS) plastic has been successfully used in static parts. The moving parts, however, must be manufactured in light metallic materials.

Regarding the management of the sensors and motors, the microcontrollers PIC (such as the ATmega family present in the Arduino family) have been offering profitable results, providing enough analogic and digital outputs with low energy operation consumption, as stated by Aubin et al. (2013) e Ates et al. (2015). Other advantages are its low-cost and easy programming with several ready and accessible libraries.

Finally, the controls are linked to the desired functions of the orthosis, and the easiest and most efficient forms are cables and springs that, together with DC motors can perform functions of extension and flexion of members precisely, as pointed out by Gasser and Goldfarb (2015).

Another important issue is the use of orthoses in conjunction with supplementary forms of movement control, such as neuromuscular electrical stimulation, which allows greater possibilities to achieve better responses from the therapies, as signalized by Leeb et al. (2010). Also, the neuromuscular electrical stimulation evokes the users' functional movements, either with severe spasticity or with spinal cord injuries.

Final Considerations

This review has shown that users of upper limb orthoses, both in rehabilitation's clinics and at home, when having the addition of specific games to simulate the movements, reached greater amplitudes of movement, compared to those whose therapeutic procedure was at the conventional way. However, most of the hand orthoses, designed with electric actuators (usually having electric motors), provide restrictions on the movements of individual fingers. This is due since they usually perform movements in the four fingers' set, keeping the thumb still. Nonetheless, in orthoses with pneumatic actuators, it is indispensable to own all the apparatus required for the movement of the pneumatic pistons, such as the air compressor and other components, limiting the independence of the movements. Additionally, due to the use of the pneumatic cylinders, this approach presents greater strength to yield those movements.

On the other hand, for the orthoses based on electric actuators, it is also necessary to consider the need for cables, batteries and connections with other devices, enabling to control the movements, as some of the orthosis here presented.

Another relevant part is the acquisition system, as the search for compressed and lightweight systems described in some of the reviewed papers here. Also, it is necessary to evaluate the way that the movements are acquired. In cases where the movement is performed by a program running on a computer, the freedom of user movements may be limited by the physical connections to the computer. Then, Wi-Fi devices arise as the best solution, in spite of a more expensive alternatives to overcome these practical restrictions.

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