

# The Influence of Dynamic Orthosis Training on Upper Extremity Function after Stroke: A Pilot Study

Rodrigo Cappato de Araújo<sup>1\*</sup>, Daniel Neves Rocha<sup>2</sup>,  
Ana Carolina Rodarti Pitangui<sup>1</sup> and Marcos Pinotti<sup>3</sup>

<sup>1</sup>Department of Physical Therapy – University of Pernambuco, Petrolina, PE, Brazil

<sup>2</sup>Department of Mechanical Engineering; Federal Institute of Minas Gerais,  
Congonhas, MG, Brazil

<sup>3</sup>Department of Mechanical Engineering; Federal University of Minas Gerais, Belo Horizonte, MG, Brazil

Submitted May 2013. Accepted for publication November 2013.

## ABSTRACT

The goal of this study was to assess the use of a dynamic orthosis on upper extremity function in chronic stroke patients. A case series approach was utilized, with provision of a training program (3x/week, 50 minutes/session for 8 weeks) and employment of a dynamic orthosis. Six volunteers with persistent hemiparesis due to a single, unilateral stroke performed task-oriented movements with the aid of a dynamic orthosis. Tests were administered before and after training. Functional capacity was assessed using the TEMPA (Test d'Évaluation des Membres Supérieurs de Personnes Âgées) test. The Wilcoxon test was used for pre-training and post-training comparisons of TEMPA scores. The volunteers showed significant improvement of upper extremity function in the performance of a bilateral task ( $p = 0.01$ ) and three unilateral tasks ( $p \leq 0.04$ ). This pilot study suggests that the dynamic orthosis associated with the performance of functional tasks can have positive outcomes regarding the improvement of functional capacity of upper extremity.

**Keywords:** electromyography, orthotic devices, rehabilitation, stroke

## 1. INTRODUCTION

According to the World Health Organization (WHO), stroke is the third-leading cause of death in industrialized countries and the leading cause of adult disability worldwide, afflicting about 15 million people annually [1–3]. The development of new therapeutic technologies has significantly decreased the mortality rate of stroke in the last several years. This factor, coupled with the high incidence of stroke, has resulted in an increase in the number of people who have and live with some degree of physical and functional disability [4].

---

\*Corresponding author: Rodrigo Cappato de Araújo, University of Pernambuco - Department of Physical Therapy, BR 203 Km 2 S/N, Vila Eduardo, Petrolina, PE – Brasil ZIP CODE 56300-000. Phone: +55 87 386-6496 Fax +55 87 3866-6470. Email: rodrigocappato@yahoo.com.br. Other authors: daniel\_neves\_rocha@hotmail.com; carolinapitangui@yahoo.com.br; pinotti@ufmg.br.

The decrease in motor function of the upper limb is a major consequence of stroke, affecting between 73% and 88% of people who survive their first stroke. Moreover, about 55% to 75% of these subjects experience, for periods up to six months or longer, impairment in performing activities of daily living [5, 6]. The impairment of these tasks results in significant physical, functional, psychological and social deficits, in addition to having a negative impact on the quality of life of these subjects [4].

The physical and functional deficits of the upper limb are often caused by weakness of specific muscles, decreased range of motion, and change in movement patterns [7], which result in change of motor coordination and decreased manual dexterity [8, 9]. In addition, the level of motor function and recovery is highly dependent on the severity and site of the lesion [10]. Quite often, subjects initially adopt a compensatory strategy to perform compromised tasks. However, the recovery process can be stimulated and shaped by rehabilitation programs that use different techniques and exercises so that motor relearning can occur [11].

Conventionally, rehabilitation programs have been conducted by therapists in hospitals or rehabilitation centers. These programs are characterized by the application of therapeutic techniques and exercises that stimulate motor relearning, aiming at increasing functional independence [12–14]. However, only 5% of the patients assessed six months after stroke have experienced full recovery of activities [15, 16].

Given the limited success of traditional rehabilitation programs in restoring upper limb function, recent studies [17–19] have investigated the use of robotic devices to assist in the recovery of motor function of the upper limb. These devices allow patients to perform specific tasks repeatedly, which has been shown by the literature to be a determining factor for the increase in motor skills and improvement in the performance of functional activities [20].

Different research groups have developed robotic devices for rehabilitation of hemiparesis patients. Among the devices developed, the most studied and used in the literature is the MIT-Manus system [21]. However, this device prioritizes the training of the shoulder and elbow joints. Another device described in the literature is the BI\_MANU TRACK [22]. This system allows the execution of the movements of the forearm (pronation and supination) and wrist (flexion and extension). However, both devices have high cost and do not allow the training of daily tasks.

While the robotic devices described in the literature show good results in the functional rehabilitation of the shoulder and elbow, recent reviews [23, 24] concluded that there is no evidence to confirm the improvement of motor function of the hand and wrist after training using these devices. Furthermore, results concerning the functional gain in performing activities of daily living are modest [24, 25]. In view of the above, the objective of this study was to assess the use of a dynamic orthosis for upper extremity function rehabilitation in chronic stroke patients. To this end, the present study used the TEMPA test which essentially assesses the functional capacity of the upper extremity during performance of activities of daily living.

## **2. METHODS**

### **2.1. Participants**

The study was conducted with six patients (four men and two women) who had a clinical diagnosis of primary ischemic stroke for at least three months. Right-handed patients who showed no significant deficits in cognition and presented motor impairment of the upper

**Table 1. Stroke clinical assessments**

Patient	Sex	Age (years)	Months				
			post-stroke	BMI	FMA	MAS-E	MAS-W
1	F	34	8	25.3	35	2	2
2	M	43	34	24.5	33	3	3
3	M	34	10	29.4	33	2	3
4	M	70	24	23.8	36	2	2
5	M	43	18	23.4	38	2	2
6	F	51	22	24.2	35	2	2
<b>Mean±SD</b>	<b>—</b>	<b>45.8 ± 13.5</b>	<b>18.8 ± 9.4</b>	<b>25.1 ± 2.2</b>	<b>35.0 ± 1.9</b>	<b>2.2 ± 0.4</b>	<b>2.3 ± 0.5</b>

F – Female. M – Male. BMI – Body Mass Index, kg/m<sup>2</sup>. FMA – Fulg-Meyer Assessment. MAS-E – Modified Ashworth Scale (Elbow). MAS-W – Modified Ashworth Scale (wrist). SD – Standard Deviation.

right limb were included. Patients who had bilateral motor sequelae, impairment on the left side or a history of experiencing two or more strokes were excluded. Volunteers who had severe spasticity (> 3 on Ashworth's modified scale) and who were not able to accomplish any of the tasks comprising the TEMPA tests were also excluded from the study. In accordance with norm 196/96 of the Brazilian National Health Council, all participants read and signed an informed consent form before undergoing the study procedures, and the study protocol was approved by the Ethics Committee of the University of Pernambuco, record CEP-UPE 041/09. Demographic and anthropometric data with baseline clinical assessment at the time of enrollment are presented in Table 1.

## 2.2. Functional Evaluation

All volunteers underwent a physical assessment in which personal and anthropometric data were collected in addition to history and questions related to stroke. The functional capacity of upper extremity was evaluated through the Brazilian version of TEMPA (Test d'Évaluation des Membres Supérieurs de Personnes Âgées) test [26]. The test consists of four bilateral tasks (open a jar and take out a spoonful of coffee; unlock a door lock, pick up and open a pill box; address and affix a stamp on an envelope; shuffle and deal playing cards) and four unilateral tasks (reach for and move a jar; pick up a pitcher and pour water into a glass; handle coins; handle small objects). The scores are based on three criteria: execution speed, functional rating and task analysis. In assessing the speed, the task is timed from the beginning to its end, and its score is represented in seconds. Functional rating refers to the autonomy of the subject while performing each task in terms of four levels: (0) task completed successfully without hesitation and difficulty, (–1) task completed with some difficulty, (–2) task partially executed or certain steps performed with difficulty, and (–3) task not completed even with assistance.

The task analysis assesses the difficulties experienced by the participants according to five criteria related to sensorimotor skills: strength, amplitude of movement, precision of large movements, fine movement precision and grip.

The functional rating score is determined by adding the scores for unilateral tasks on the right (0 to –12), on the left (0 to –12), and for the bilateral tasks (0 to –12), yielding

a total functional rating score between 0 and -36. An evaluation is also performed for the five dimensions of the analysis session of the tasks. Considering that 'precision of fine movements' is not measured by such tasks as 'pick up and carry a pot' and 'pick up a pitcher and pour water' and 'force' is not assessed in the tasks 'address and affix a stamp on an envelope', 'pick up and carry small objects', 'handle coins' and 'shuffle cards', task analysis scores may vary from 0 to 150.

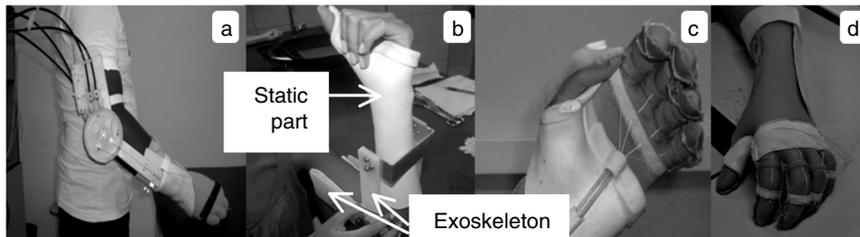
The total score (0 to -186) represents the sum of functional rating and task analysis. Observing the dimensions assessed in each task, it is possible to obtain the following scores: Task 1 (open a jar, take out a spoonful of coffee): 0 to -18; Task 2 (unlock a lock; pick up and open a pill box): 0 to -18; Task 3 (address an envelope and affix a stamp): 0 to -15; Task 4 (shuffle and deal cards from a deck): 0 to -15; Task 5 (reach for and move a jar): 0 to -30; Task 6 (pick up a pitcher and pour water in a glass): 0 to -30; Task 7 (handle coins): 0 to -30; and Task 8 (handle small objects): 0 to -30. Unilateral tasks present scores varying from 0 to -30, since in this case the scores obtained in the evaluation of the two limbs are added. However, this study did not consider the runtime and scores of unilateral tasks performed with the healthy limb [27]. Thus, the scores ranged from 0 to -126.

Although the original scale always results in negative scores, in which zero indicates the absence of disability and the negative values indicate disability, for the purposes of statistical analysis, we used the absolute values, i.e., values independent of the sign. Thus, for this study, higher values correspond to higher disability. In a previous study [26], adequate intra- and inter-examiner reliability was demonstrated (ICC 0.70 – 1.00) for the TEMPA (Brazilian version) scores applied for patients with mild motor deficits (FMA < 50).

### 2.3. Dynamic Orthosis Device

The dynamic orthosis, previously described by Araújo et al. [28], consists of an exoskeleton, static orthosis, functional glove, control unit, and electromechanical actuators (Figure 1).

The exoskeleton is a mechanical structure formed by two segments made of nylon positioned along the arm and forearm and connected by a pivot shaft. A single pulley is fixed on the mechanical structure of the exoskeleton with the center coinciding with the rotation axis of the elbow joint. Rotation of the pulley, generated by the force of the mechanical actuators, is responsible for flexion and extension of the elbow joint.



**Figure 1.** Exoskeleton and static orthosis (A and B); Glove: ventral view (C) and dorsal view (D).

The range of motion was preset between  $10^{\circ}$  –  $110^{\circ}$  of flexion, avoiding extreme ranges of flexion and extension so that there would not be overload and stress on the ligaments and joint structures.

The static orthosis were manufactured with thermoplastic material and were used to stabilize and position the arm and forearm of the participant. Moreover, the static part fixed on the forearm was also responsible for stabilization of the articulation of the wrist in  $20^{\circ}$  of extension and the thumb in  $20^{\circ}$  of abduction, in order to allow pincer movement. For better grip and support of the orthosis, the static parts were fixed and adjusted with Velcro.

For the performance of the flexion and extension of the fingers, Lycra gloves were made for each participant, using strips of inelastic material that served as the attachment point and guide for artificial tendons, thus reproducing the system of tendons and tunnels of the human hand. The artificial tendons (DyneemaVexterbraided line of 30 lbs) were responsible for transmitting the motion of electromechanical actuators for the fingers, promoting flexion and extension movements of the fingers.

Two actuator modules were responsible for flexion and extension of the elbow and fingers. The actuator modules were placed on a bench and were composed of an electromechanical actuator and a drive system. The electromechanical actuator corresponds to the DC motor coupled to the drive system and triggered by a control module consisting of an electrical circuit. Differential simple active electrodes (DatahominisLtda, Brazil) were used for the acquisition of myoelectric signals. These signals were processed by a control unit, responsible for the triggering and control of the torque produced by the electromechanical actuators in the joints. The flexion and extension movements of the elbow were controlled by the electromyographic (EMG) signal of the biceps and triceps muscles, respectively. The opening and closing movements of the hand were controlled by EMG signals of the common extensor muscles of the fingers and flexor digitorum superficialis, respectively.

To check the operation of the control circuit, a visual feedback system formed by light emitting diodes (LED) was used. Each channel has an LED at its output that is triggered when the selected muscle group is contracted. The system has controls for power circuitry and motors. In addition, each channel had a key enabled power button for passive therapy mode and control to adjust the gains of the circuit allowed to change the threshold for activation of the motor, enabling to adjust the system to the needs of each patient, as well as to allow the progression of the training.

The dynamic orthosis made possible the development of passive and actively-assisted therapies. In the actively assisted mode, upon a signal generated by the EMG activity of a specific muscle, the orthosis completed the movement which the patient intended but was unable to perform. In the passive mode, the therapist triggers the external engines to generate the desired movement. This mode of therapy was used at the beginning of the training, with the function to guide and instruct the motions to the patients.

#### **2.4. Rehabilitation Program**

Upon completion of the functional assessment, participants went through a rehabilitation program involving using the aforementioned dynamic orthosis associated with functional training. [28]. Training consisted of twenty-four sessions, performed

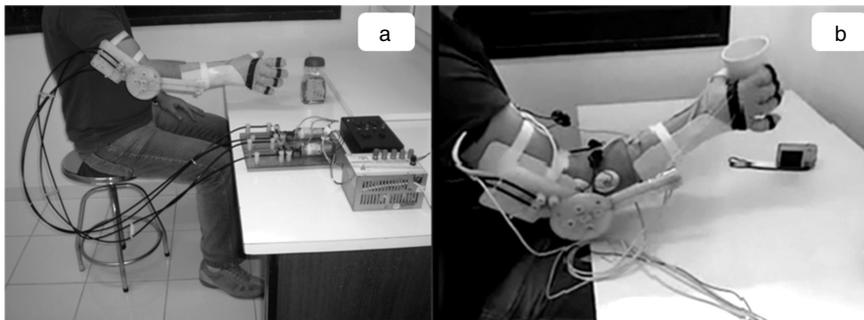
three times a week for eight weeks, with each session lasting for 50 minutes. The rehabilitation program of the participants in this study was conducted by the same physiotherapist for every session. At the beginning of the program, all patients received instructions on the use of the device.

Initially, the dynamic orthosis was fitted on the patients and the myoelectric sensors were installed in the appropriate places. Patients were then instructed to perform the movements of flexion and extension of the fingers and elbow, so as to regulate the activation thresholds of each actuator in the electrical circuit. During the first four sessions, the participants only performed the elbow and finger movements (assisted active therapy) repeatedly for about 25 minutes. After this period of familiarization and training, functional tasks, such as picking up and moving objects on a table, were included in the program. For this task, patients were sitting in front of a table and were told to pick up different objects (plastic glasses, two balls of different sizes and weights, and digital camera), bring them close to their face and return them back to the table (Figure 2). To perform these tasks, it was necessary to perform elbow and hand movements in a coordinated fashion. In order to facilitate the progression of treatment, the number of repetitions increased and the locations of the objects on the table were changed.

These tasks were performed for about 20 minutes depending on the physical limits of each participant. However, at most, each volunteer performed three sets (five repetitions/set) with each object. The objects were placed on the table in three different locations: 20, 40 and 60 centimeters, respectively, from the edge. During the training period, patients did not receive any other upper extremity treatment. Only exercises for trunk, lower limbs and gait training were administered, twice a week. Upon completion of the rehabilitation program, all patients were reevaluated.

### 2.5. Data Analysis

All statistical analyses were performed using the statistical package SPSS (version 10.0). Prior to analyzing each variable, data distribution normality was tested by the Shapiro-Wilk test. The Wilcoxon test was used for pretraining and posttraining comparisons of the TEMPA scores. For all analyses,  $p \leq 0.05$  was considered significant.



**Figure 2.** Subject using the dynamic orthosis: Passive mode, without EMG (A) and Active-Assisted mode, with EMG (B).

### 3. RESULTS

The results of the TEMPA test showed that the group of participants undergoing training with the dynamic orthosis showed improvement in scores for four tasks, and also a decrease in execution time of two tasks, thus indicating improved functional capacity of upper limb in one bilateral task (task 4: shuffle and deal cards from a deck) and three unilateral tasks (tasks 5: reach for and move a jar; 6: pick up a pitcher and pour water in a glass; and 7: handle coins). The other bilateral tasks (task 1: open a jar, take out a spoonful of coffee; task 2: unlock a lock, pick up and open a pill box; and task 3: address an envelope and affix a stamp) and one unilateral task (task 8: handle small objects) did not show significant difference (Table 2).

**Table 2. Mean values of TEMPA scores, before and after training**

	Pre-training	Post-training	<i>p</i>
Task 1			
Score	7.0 ± 1.4	4.8 ± 1.8	0.06
Time (s)	24.9 ± 6.0	22.1 ± 4.1	0.33
Task 2			
Score	9.5 ± 0.9	6.5 ± 1.9	0.06
Time (s)	45.7 ± 9.3	32.0 ± 4.7	0.06
Task 3			
Score	7.6 ± 0.8	5.3 ± 1.3	0.06
Time (s)	43.2 ± 21.9	30.6 ± 17.1	0.13
Task 4			
Score	7.3 ± 1.2	5.1 ± 1.6	0.01*
Time (s)	56.9 ± 16.1	46.9 ± 19.3	0.09
Task 5			
Score	6.0 ± 2.2	4.3 ± 2.5	0.01*
Time (s)	5.1 ± 0.8	4.0 ± 0.5	0.04*
Task 6			
Score	7.1 ± 1.8	4.6 ± 2.6	0.04*
Time (s)	21.7 ± 6.5	16.1 ± 3.3	0.03*
Task 7			
Score	8.1 ± 1.6	5.8 ± 2.1	0.03*
Time (s)	28.8 ± 14.5	21.5 ± 16.2	0.11
Task 8			
Score	6.5 ± 2.0	5.6 ± 2.3	0.08
Time (s)	21.9 ± 6.3	14.1 ± 3.1	0.22
Total			
Score	61.1 ± 12.2	43.5 ± 16.2	0.01*
Time (s)	231.4 ± 80.2	174.6 ± 52.6	0.03*

The values shown are mean ± standard deviation.

The scores are calculated as the sum of the functional rating and task analysis.

\*Indicates statistically significant difference between pre- and post-training data.

In addition, a significant improvement of scores and total time of performance of tasks (Table 2) were observed. In absolute values, there was an average decrease of approximately 18 points, which means a decrease of 29% in total scores. Regarding the execution time, it was possible to observe a decrease of 48 seconds, which indicates an improvement of 16.5%.

#### 4. DISCUSSION

The present study aimed at evaluating the effect of a training program using a dynamic orthosis for physical rehabilitation, with an emphasis on improving manual dexterity and performance of activities of daily living (ADL) in participants with upper limb motor sequelae as a result of stroke. The results of this study indicated that the tested device can benefit functional capacity of upper extremity in patients with hemiparesis.

The initial values of the TEMPA test revealed that, at baseline, the participants had significant level of impairment and a significantly compromised capability and dexterity in performing manual tasks. As noted in the results, the participants had scores on individual TEMPA tasks ranging between 6 and 9.5, while the mean total score was 61.1 points. According to studies that identified reference values for TEMPA tests, healthy individuals have a zero score on all tasks, which means that tasks are performed successfully without any sign of compromised sensorimotor skills [29].

Although impairment of upper limb function and manual dexterity have been observed through TEMPA scores in the participants of the current study, comparison of the current results with those in the literature data is complex, because previous studies [27, 30, 31] were limited to evaluating the variable “run time”. Regarding the “run time” variable, the current results show that the participants performed TEMPA tasks in times ranging between 5.1 and 56.9 seconds, depending on the task, while in previous studies [29, 32], the values considered normal range from 1.7 to 13.9 seconds in young individuals (20 – 44 years), and between 1.5 to 18.1 seconds in the elderly (above 60 years old).

Furthermore, an average time of 52 seconds to complete all TEMPA tasks is described in the literature for healthy subjects [29]. In this study, the average execution time for all TEMPA tasks was 231.4 seconds. Platz et al. [27, 31] reported an average TEMPA execution time ranging between 210 and 230 seconds in patients classified with mild paresis. These same volunteers presented average values on the Fugl-Meyer scale ranging between 23.3 and 26.2 points, while the subjects in our study presented values between 33 and 38 points, which according to previous studies [33, 34] indicates mild paresis, since these values are within the range of mild motor compromise (21 – 55 points on the FMA scale) described by Fugl-Meyer [35].

After training using the dynamic orthosis, the participants’ functional capacity of upper limbs was improved, as shown by an average decrease in the total TEMPA score by approximately 18 points, in addition to a reduction of total execution time by about 48 seconds. Platz et al. [31] observed an improvement in TEMPA execution time in patients with mild hemiparesis after three weeks of treatment. That study revealed a decrease of 16.5 seconds in patients who underwent conventional rehabilitation, and a decrease of 41.4 seconds in patients who underwent a program featuring rehabilitation using specific training targeting arm motor skills.

In another study, Platz et al. [27] evaluated the effects of intensive training, performed daily for three consecutive weeks, and showed that patients treated with conventional therapy and training targeting sensorimotor impairments showed a decrease of 27.8 and 31.1 seconds in TEMPA execution time, respectively. No direct comparison can be made between our results and the previous results, our results show that the proposed device provided similar benefits as other techniques. However, it is important to note that in studies conducted by Platz et al. [27, 31], the best results were achieved by combined techniques. In this sense, their results corroborate the present study data, since the gains observed in our study may have been due to training tasks of reach and grip associated with the use of the orthosis.

Recently, Gijbels et al. [30] evaluated the effect of a training program using a robotic device known as *The Armeo Spring* in the rehabilitation of motor function and manual dexterity of patients with paresis in both upper limbs resulting from multiple sclerosis. This device features an exoskeleton that facilitates assisted active therapy of shoulder, elbow and forearm movements in a virtual environment. After 24 training sessions, a decrease of about 23.6 seconds in TEMPA run time was observed. Although we found no other studies using TEMPA to evaluate the effect of assisted technologies on the treatment of patients with motor sequelae resulting from stroke, the study by Gijbels et al. [30] supports the possible positive effects of using dynamic orthoses in the motor rehabilitation programs. These devices allow repeated execution of tasks in a controlled and systematic mode, which has been demonstrated to be a determining factor in the facilitation of cortical reorganization, with a concomitant increase in motor function [34].

In the present study, we observed a 29% improvement in the total score and a 16.5% improvement in the TEMPA test execution times. Unlike the FMA that provides evidence confirming that changes greater than 10% are considered clinically improved [37, 38], reference values that indicate clinical improvement have not been established in the literature for TEMPA tests applied to stroke patients. Although a previous study shows strong correlation between the FMA and TEMPA [26], there is no direct evidence that the improvement observed in this study is clinically relevant. Future studies are warranted to assess this issue.

Finally, the present TEMPA test results revealed significant improvements in four of eight tasks tested, including the bilateral test of shuffling and dealing cards from a deck, and three other unilateral tasks, such as reaching for and moving a jar, handling a pitcher and pouring water into a glass and handling coins. The different results among the tasks may be related to the specificity of the training.

Regarding specificity, the fact that the participants performed about 20 minutes of training (reach and grab tasks) per session, activities which are predominantly unilateral tasks in the TEMPA test, may explain the better performance in tasks 5, 6 and 7. This fact corroborates Platz et al.'s results [27, 31] that in addition to intensity, the most important factor in improving manual dexterity is training specificity. In addition, the current study sample was composed mostly of middle-aged adults and only one senior. This aspect may have positively influenced the outcome of the study, since age is a determining factor in the process of cortical reorganization.

The present study has some limitations, mainly related to sample size and lack of a control group. Furthermore, this study only examined a specific test; evaluation of other

aspects related to motor performance is needed. Thus, despite the positive results demonstrated, there is a clear limitation in stating that the orthosis training was the main factor for the improvement of functional capacity of the upper limb. Studies with larger samples and a control group are needed to elucidate whether the effect observed is indeed related to training with the orthosis or is simply influenced by the effect of time, considering that the study evaluated a relatively young sample and a few months after stroke. Finally, it is suggested that randomized controlled clinical trials be conducted in the future to investigate and compare the possible benefits of single and combined rehabilitation programs.

## 5. CONCLUSION

The results of this pilot study showed that the dynamic orthosis resulted in an improvement in scores of TEMPA test. The results suggest that the device can benefit functional rehabilitation of patients with hemiparesia. Further randomized controlled clinical trials are required to confirm the clinical efficacy of this device.

## ACKNOWLEDGEMENTS

This work was supported by The National Council for Scientific and Technological Development (CNPq), Brazil.

## CONFLICT OF INTEREST

The authors indicated no potential conflicts of interest.

## REFERENCES

- [1] Zhang Y, Chapman AM, Plested M, Jackson D, Purroy F. The Incidence, Prevalence, and Mortality of Stroke in France, Germany, Italy, Spain, the UK, and the US: A Literature Review. *Stroke Research and Treatment*, 2012, 2012:436125.
- [2] Mukherjee D, Patil CG. Epidemiology and the global burden of stroke. *World Neurosurgery*, 2011, 76(6):S85–90.
- [3] Brainin M, Bornstein N, Boysen G, Demarin V. Acute neurological stroke care in Europe: results of the European Stroke Care Inventory. *European Journal of Neurology*, 2000, 7:5–10.
- [4] Norrving B, Kissela B. The global burden of stroke and need for a continuum of care. *Neurology*, 2013, 15(80):S5-12.
- [5] Carod-Artal J, Egido JA, Gonzalez JL, Varela de Seijas E. Quality of life among stroke survivors evaluated 1 year after stroke: experience of a stroke unit. *Stroke*, 2000, 31:2995–3000.
- [6] Clarke P, Marshall V, Black SE, Colantonio A. Well-being after stroke in Canadian seniors: findings from the Canadian Study of Health and Aging. *Stroke*, 2002, 33:1016–1021.
- [7] Patten C, Condliffe EG, Dairaghi CA, Lum PS. Concurrent neuromechanical and functional gains following upper-extremity power training post-stroke. *Journal of neuroengineering and rehabilitation*, 2013, 21(10):10–1.
- [8] Kong KH, Lee J. Temporal recovery and predictors of upper limb dexterity in the first year of stroke: a prospective study of patients admitted to a rehabilitation centre. *NeuroRehabilitation*, 2013, 32(2):345–50.
- [9] Lindberg PG, Roche N, Robertson J, Roby-Brami A, Bussel B, Maier MA. Affected and unaffected quantitative aspects of grip force control in hemiparetic patients after stroke. *Brain Research*, 2012, 3(1452):96–107.
- [10] Dijkhuizen RM, van der Marel K, Otte WM, Hoff EI, van der Zijden JP, van der Toorn A, van Meer MP. Functional MRI and Diffusion Tensor Imaging of Brain Reorganization After Experimental Stroke. *Translational stroke research*, 2012, 3(1):36–43.

- [11] Dispa D, Lejeune T, Thonnard JL. The effect of repetitive rhythmic precision grip task-oriented rehabilitation in chronic stroke patients: a pilot study. *International journal of rehabilitation research*, 2013, 36(1):81–7.
- [12] Michielsen ME, Selles RW, van der Geest JN, Eckhardt M, Yavuzer G, Stam HJ, Smits M, Ribbers GM, Bussmann JB. Motor recovery and cortical reorganization after mirror therapy in chronic stroke patients: a phase II randomized controlled trial. *Neurorehabil Neural Repair*, 2011, 25(3):223–33.
- [13] Coupar F, Pollock A, Rowe P, Weir C, Langhorne P. Predictors of upper limb recovery after stroke: a systematic review and meta-analysis. *Clinical Rehabilitation*, 2012, 26(4):291–313.
- [14] Liebigt S, Schlegel N, Oberland J, Witte OW, Redecker C, Keiner S. Effects of rehabilitative training and anti-inflammatory treatment on functional recovery and cellular reorganization following stroke. *Experimental Neurology*, 2012, 233(2):776–82.
- [15] Kwakkel G, Kollen BJ. Predicting activities after stroke: what is clinically relevant? *International Journal of Stroke*, 2013, 8(1):25–32.
- [16] Kwakkel G, Kollen BJ, van der Grond J, Prevo AJH. Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. *Stroke*, 2003; 34:2181–6.
- [17] Frisoli A, Procopio C, Chisari C, Creatini I, Bonfiglio L, Bergamasco M, Rossi B, Carboncini M. Positive effects of robotic exoskeleton training of upper limb reaching movements after stroke. *Journal of NeuroEngineering and Rehabilitation*, 2012, 9:36.
- [18] Lambercy O, Dovat L, Yun H, Wee SK, Kuah CWV, Chua KSG, Gassert R, Milner TE, Teo CL, Burdet E. Effects of a robot-assisted training of grasp and pronation/supination in chronic stroke: a pilot study. *Journal of NeuroEngineering and Rehabilitation*, 2011, 16(8):63.
- [19] Kan P, Huq R, Hoey J, Goetschalckx R, Mihailidis A. The development of an adaptive upper-limb stroke rehabilitation robotic system. *Journal of NeuroEngineering and Rehabilitation*. 2011, 16(8):33.
- [20] Mehrholz J, Hädrich A, Platz T, Kugler J, Pohl M. Electromechanical and robot-assisted arm training for improving generic activities of daily living, arm function, and arm muscle strength after stroke. *Cochrane database of systematic reviews*, 2012, 13(6):CD006876.
- [21] Krebs HI, Hogan N, Aisen ML, Volpe BT. Robot-aided neurorehabilitation. *IEEE Transactions on Rehabilitation Engineering*, 1998, 6:75–87.
- [22] Hesse S, Kuhlmann H, Wilk J, Tomelleri C, Kirker SG. A new electromechanical trainer for sensorimotor rehabilitation of paralysed fingers: a case series in chronic and acute stroke patients. *Journal of NeuroEngineering and Rehabilitation*, 2008, 5:21.
- [23] Teasell R, Foley N, Salter K, Bhogal S, Jutai J, Speechley M. Evidence-based review of stroke rehabilitation: executive summary, 12th edition. *Top Stroke Rehabilitation*, 2009, 16(6):463–88.
- [24] Norouzi-Gheidari N, Archambault PS, Fung J. Effects of robot-assisted therapy on stroke rehabilitation in upper limbs: systematic review and meta-analysis of the literature. *Journal of rehabilitation research and development*, 2012;49(4):479–96.
- [25] Mehrholz J, Platz T, Kugler J, Pohl M. Electromechanical and robot-assisted arm training for improving arm function and activities of daily living after stroke. *Cochrane Database System Review*, 2008, CD006876.
- [26] Michaelsen SM, Natalio M, Silva AG, Pagnussat AS. Reliability of the translation and adaptation of the Test d'Évaluation des Membres Supérieurs des Personnes Âgées (TEMPA) to the Portuguese language and validation for adults with hemiparesis. *Brazilian Journal of Physical Therapy*, 2008, 12:511–9.
- [27] Platz T, Van Kaick S, Mehrholz J, Leidner O, Eickhof C, Pohl M. Best Conventional Therapy Versus Modular Impairment-Oriented Training for Arm Paresis After Stroke: A Single-Blind, Multicenter Randomized Controlled Trial. *Neurorehabilitation Neural Repair*, 2009, 23:706–716.
- [28] de Araújo RC, Junior FL, Rocha DN, Sono TS, Pinotti M: Effects of intensive arm training with an electromechanical orthosis in chronic stroke patients: a preliminary study. *Archives of Physical Medicine and Rehabilitation*, 2011, 92:1746–53.
- [29] Nedelec B, Dion K, Correa JA, Desrosiers J. Upper extremity performance test for the elderly (TEMPA): normative data for young adults. *Journal of Hand Therapy*, 2011, 24:31–42.

- [30] Gijbels D, Lamers I, Kerkhofs L, Alders G, Knippenberg E, Feys P. The Armeo Spring as training tool to improve upper limb functionality in multiple sclerosis: a pilot study. *Journal of NeuroEngineering and Rehabilitation*, 2011, 24:8:5.
- [31] Platz T, Winter T, Müller N, Pinkowski C, Eickhof C, Mauritz KH. Arm ability training for stroke and traumatic brain injury patients with mild arm paresis: a single-blind, randomized, controlled trial. *Archives of Physical Medicine and Rehabilitation*, 2001, 82:961–8.
- [32] Desrosiers J, Hébert R, Bravo G, Dutil E. Upper extremity performance test for the elderly (TEMPA): normative data and correlates with sensorimotor parameters. Test d'Evaluation des Membres Supérieurs de Personnes Agées. *Archives of Physical Medicine and Rehabilitation*, 1995, 76:1125–9.
- [33] Michaelsen SM, Levin MF. Short-term effects of practice with trunk restraint on reaching movements in patients with chronic stroke: a controlled trial. *Stroke*, 2004, 35:1914–1919.
- [34] Michaelsen SM, Dannenbaum R, Levin MF. Task-specific training with trunk restraint on arm recovery in stroke: randomized control trial. *Stroke*, 2006, 37:186–192.
- [35] Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. A method for evaluation of physical performance. *Scandinavian Journal of Rehabilitation Medicine*, 1975, 7:13–31.
- [36] Liepert L, Uhde I, Graf S, Leidner O, Weiller C. Motor cortex plasticity during forced-use therapy in stroke patients: a preliminary study. *Journal of Neurology*, 2001, 248:315–21.
- [37] Stein J, Narendran K, McBean J, Krebs K, Hughes R. Electromyography controlled exoskeletal upper-limb-powered orthosis for exercise training after stroke. *American Journal of Physical Medicine & Rehabilitation*, 2007, 86:255–261.
- [38] Van der Lee JH, Wagenaar RC, Lankhorst GJ, Vogelaar TW, Devillé WL, Bouter LM. Forced use of the upper extremity in chronic stroke patients: results from a single-blind randomized clinical trial. *Stroke*, 1999, 30:2369–75.



**Hindawi**

Submit your manuscripts at  
<http://www.hindawi.com>

