EFFECTS OF A ROBOTIC THERAPY GAME ON THE SENSORY-MOTOR CONTROL OF HEALTHY ADULTS' ANKLE

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Abstract. Robotic device deployment used for the recovery of people with neurologic diseases is increasing. However, there are insufficient guidelines to prescribe rehabilitation therapy of the lower limbs. The aim of the study was to verify whether a single session of robotic therapy promotes short-term ankle adaptations, influencing the sub-maximum torque maintenance of ankle (steadiness condition) in health individuals. Methods: This was a transversal pilot study on a convenience sample of participants (n = 14). Balance and gait function were measured. Steadiness tests were assessed using dynamometry. For submaximal sensorimotor control analysis (Steadiness), the standard deviation, coefficient of variation and root mean standard error (RMSE) were recorded. Results: Only the dorsiflexion movement presented significant differences for SD (F=7.10; p=0.01) and CV (F=6.20; p=0.02). Conclusion: People with health individuals presented short-term performance gains in submaximal torque maintenance after a single robotic therapy session.

Palavras chave: Neurological Rehabilitation. Videogame therapy. Anklebot. Ankle rehabilitation. Assistive Technology.

1. INTRODUCTION

Using robotic systems to complement conventional post-rehabilitation programs is a promising resource. Robotic devices can provide high-intensity, repetitive, specific and oriented task practice. Clinical protocols involving robotic therapy associated with serious games are designed according to the deficits in motor control by following therapy objectives. To ensure that the therapeutic protocols are effective, it is first necessary to check for adverse effects and the level of difficulty. Verifying its effects in healthy individuals is a good starting point to test a protocol with the high intensity characteristic, i.e. a high number of repetition.

However, the criteria for establishing these protocols are not listed in a single document. Guidelines do not exist to help robot and game rehabilitation professionals. There is no organization that can govern these standards or is able to create, standardize and oversee the rules and procedures related to robotic therapy. What are the first clinical steps that we should follow to develop a novel protocol in a serious game? What usually happens is that games are developed based on previous games that have shown favorable results according to a therapeutic goal. However, many studies do not present clear therapeutic goals or contemplate prioritizing the functional needs. From one article to another the groups are elaborating and improving the protocols` reasoning.

For this work, the protocol was developed with the aim of improving the ankle motor control. This protocol promotes a safe therapeutic environment with the sitting patient, and can be applied to patients with balance deficits. Emphasis was placed on impedance control, with the fixed speed criterion.

They allow for varied and adjustable levels of assistance to facilitate impaired limbs (Roy et al. 2009; Forrester, 2013). Furthermore, videogames and biofeedback interactions can promote additional motor control adjustments and improve motivation, optimizing task performance in individuals with hemiparesis (Forrester et al., 2013; Lohse et al., 2014). Using robots to treat post-stroke patients has come to the forefront over the last decade, however there is little information in the literature on how this type of therapy can affect sensorimotor performance and relearning (Veerbeek et al. 2016) . In addition, to the best of our knowledge, there are no findings about specifics tests that measure ankle adaptations (Zhang et al. 2013; Ellis et al. , 2016).

Accordingly, the aim of the study was to verify whether a single session of robotic therapy promotes short-term ankle adaptations, influencing the sub-maximum torque maintenance of ankle (steadiness condition) in health adults. The latter are individuals who have not been affected by a stroke, are not sedentary, and were matched to the post-stroke patients according to age, BMI (body mass index) and gender. The hypothesis was that the single robotic-assisted session promotes short-term adjustments in motor control of ankle during submaximal torque.

2. MATERIAL AND METHODS

2.1. Ethical Guidelines

The study was conducted according to the guidelines and standards for human research (Resolution 196/1996, the National Health Council) and it was approved by the local ethics committee (report no.: 527.556/2014). This was a double-arm pilot study.

2.2. Experimental Design

The following inclusion criteria were considered: men or women aged between 50 and 75 years; independent overground walking. The participants had to score greater than 8 on the Physical Activity Questionnaire Basal, which indicates they were not sedentary (Thorp A et al., 2011). Furthermore, individuals performed physical activity (mainly aerobic activities) at least 3 times a week. No further criteria regarding the physical activity level were used. The exclusion criteria were: clinical signs of severe heart failure or chronic metabolic disease; severe cognitive or communication impairments; minimum score on the Mini-Mental State Examination according to the education level (Enzinger et al., 1975); a history of lower limb injuries, deformity or contractures of the ankle joint; a smaller range of motion than 10º for dorsiflexion and 20º for plantarflexion; sensory deficits and neglect absence defined by clinical exams.

2.3. Participants

The subjects were recruited of local community. Thus, 28 individuals took part in the study. The volunteers (n=14) also consisted of 12 men and 2 women. These received information about the importance of doing regular physical activity.

2.4. Procedure and Measuring Instruments

The evaluations were performed as follows: on the first day, screening was performed to apply the inclusion and exclusion criteria (clinical assessment), as well as functional tests. The second day was for becoming familiarized with the evaluation protocol of the robotic session (the protocol of robotic assisted therapy associated to videogame was defined as a session). After one week, the evaluation protocol was carried out.

2.4.1. Balance and mobility

The balance and mobility were assessed using multiple scales and tests: the Berg Balance Scale (Blum, Korner-Bitensky, 2008) and the 10-Meter walking test (Jonsdottir, Cattaneo, 2007). The familiarization procedures were conducted as follows: 10-meter walking test, maximum voluntary contraction, steadiness and robotic assisted therapy. The 10-meter walking test was used to verify functional task (gait performance), maximum voluntary contraction to calculate the sub-maximum torque (target torque), steadiness to verify the ankle sensorimotor control during maintenance of the sub-maximum torque (target torque). One week after familiarization procedures, the same assessment protocol was applied in pre and post robotic assisted therapy session times. In addition, steadiness and 10-meter walking tests were redone after the robotic therapy. The sub-maximum torque value obtained during pre-therapy was used in the post-therapy steadiness test for comparison purposes.

2.4.2. 10-meter test

Participants were instructed to perform a preferred walking speed or comfortable walk with their usual walking device. The participant time was recorded for the middle 10-m of the 12-m walkway, and the average gait velocity was calculated. Three trials were carried out and the average was recorded for data analysis. A brief rest was given in between trials (Jonsdottir, Cattaneo, 2007; Silva-Couto et al., 2013).

2.4.3. Steadiness test

The higher peak torque of three CIVM repetitions was used to calculate the target strength (20% of CIVM) (Kato et al., 2011) The submaximal sensorimotor control was evaluated during five repetitions and conducted by visual feedback, displayed as a horizontal line for 20 seconds, with a 60 second rest between sets. Only three repetitions were used in the analysis. The first and last sets were excluded. Considering the initial and final motor adjustments, the three first seconds and the last second were excluded. The low-pass second-order, Butterworth filter, with a cut-off frequency of 7Hz was used. The following variables were calculated: Standard deviation (SD), Coefficient of variation (CV), and root mean square error (RMSE). Standard deviation (SD) is the absolute measurement of the amplitude fluctuation torque. Coefficient of variation (CV) is a measure of torque fluctuations expressed as a percentage of average torque (CV=SD/
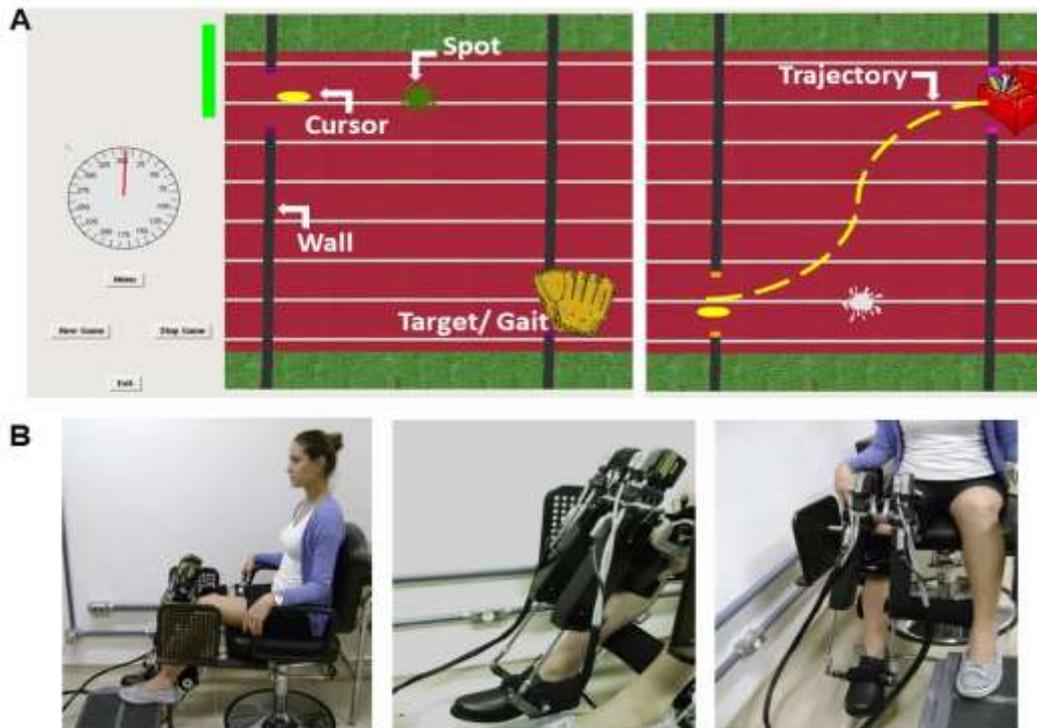
Figure 1. A) Game interface and B) Anklebot device

average torque x 100). SD and CV values for torque fluctuation were used to probe the subject's ability to sustain a steady submaximal contraction at a constant torque level. The root mean square error (RMSE) is the square of the vertical distance between the target torque and generated torque (Santos et al., 2016)

3. Ankle Robotic therapy (Anklebot) and videogame

3.1. Anklebot device

The Anklebot robotic system (Interactive Motion Technologies, Inc., Watertown, MA, USA) is a wearable and backdrivable system that can be used in a seated position or during walking. It allows actuation and sensing within the normal motion range of the ankle joint (Roy et al., 2009). Anklebot uses an impedance controller with adjustable stiffness and damping.

3.2. Anklebot setup

Subjects were then introduced to the videogame "race" that was subsequently used to assess the paretic ankle motor control (Fig 1A). The patient was positioned according to the description of Roy et al. (2009). The paretic lower limb was positioned at ~45° on a cushioned knee support, isolating the foot to move freely about the ankle (Fig 1B). The chair was positioned at 1.5 meters from the computer screen (Forrester, Krebs, Macko , 2011)

3.3. Videogame

The movements were visually promotes (movement initiated by visual feedback) and the objectives were presented in a videogame that reproduces an obstacle course. The ankle was free to move in the frontal plane, the patient controlled the ankle during movements of dorsiflexion and plantar flexion to achieve the targets. This interactive approach used an impedance controller. The Anklebot control functioned as a cursor showing "up" or "down". The individual was directed, along a trajectory, by target in two vertical levels corresponding to 10° dorsiflexion and 20° plantarflexion degrees. Assistance at the beginning of the movement was provided when necessary, allowing individuals to achieve the target, i.e., if the subject was not able to start moving after two seconds, the Anklebot provided torque to initiate the movement towards the target. (Roy et al., 2009; Forrester et al., 2014)

3.4. Repetition protocol and varying impedance waves

Three hundred and fifty ankle movements were distributed in seven blocks and there was a 3.5-second interval between each target. The protocol comprised switched robotic-assistance levels that were modified at each block of 50 movements/targets. The first and the last block were exempt from any robotic assistance. At the second to fourth blocks, there was a gradual impedance increase of 50Nm/rad. The fifth and sixth blocks presented gradual impedance decrease. Thus, the following impedance sequence was applied: 0Nm/rad ► 50Nm/rad ► 100Nm/rad ► 150Nm/rad ► 100Nm/rad ► 50Nm/rad ►0Nm/rad.

3.5. Game score

The total score recorded in each block was 1500 points. The player´s aim was to move through the gate passage and reach the target object (30 points). Bumping the cursor on game obstacles on the wall (-20 points) and on the spots on the race track (-10 points) were the error possibilities. At the end of the session, the total number of errors and correct answers were shown. During the game, according to the performance of the player, a bar remained green or red as a visual feedback. There was no difference between between the blocks ($p \geq 0.05$).

3.6. Data Analysis

Data were tested for normality and homogeneity (Shapiro-Wilk and Levene tests, respectively). The demographic and functional data (parametric data), were applied Independent t-test (evaluation: pre and post-robotic assisted session) were used to verify the effect of the ankle robotic-assisted session. The Wilcoxon (non parametric data) were used for the following variable game score. Steadiness variables (parametric data), Anklebot® and Biodex data processing were performed using MatLab software (v.7.0.1) and SPSS for all statistics analysis (v.17). The GraphPrism (v.7) software was used to develop the graphs.

5. RESULTS

5.1. Demographic and Functional data

The descriptive data (e.g., demographic and functional data) are presented in Table 1.

	Subjects (n= 14)
Gender (Male/Female)	(M:11/ F:2)
Age (years)	64 (74-53)
Height (meters)	1.66 (1.83-1.50
Body Weight (Kg)	70 (94-55)
Body Mass Index (Kg/m^2)	25.4 (30.3-20.8)
Mini Mental	28 (29-24)
Berg Balance Scale	56 (56-52)

Measurements are reported as median (maximum and minimum values).

Table 1. Characteristics of study subjects

5.2. 10-meter Walking Test

The average gait velocities were 2.01±0.4m/s in the pre-robotic session and 1.9±0.3m/s in the post-robotic session.

5.3. Game score

No significant differences were identified between blocks. See table 2.

Table 2. Game score

1° block (0Nm/rad)	2° block (50Nm/rad)	3° block (100Nm/rad)	4° block (150Nm/rad)	5° block (100Nm/rad)	6° block (50Nm/rad)	7° block (0Nm/rad)
1297.5±285	1425.0±52	1422.5±93	1431.6±79	1445.8±50	1405±158.2	1312.33±380

Impedance or exoskeleton assistance K= Newton meters per radians (Nm/rad). The comparison between game scores during several blocks did not present significant differences (p≥0.005).

5.4. Steadiness

Only the dorsiflexion movement presented significant differences for SD (p=0.01) and CV (p=0.02). See Table 3.

Table 3. Steadiness variables during dorsiflexion and plantar flexion after and before robotic session.

	PRE SESSION			POST SESSION		
	SD	CV	RMSE	SD	CV	RMSE
DF	1.27 (±0.60)	11.87 (±6.10)	2.85 (±0.32)	1.00 (±0.77) [†]	9.14 (±0.77) [†]	2.77 (±0.34)
PF	0.56 (±0.45)	4.65 (±4.36)	2.89 (±0.47)	0.80 (±0.58)	5.28 (±4.24)	2.80 (±0.34)

SD= Standard deviation; CV= Coefficient of variation; RMSE= root mean square error; DF=Dorsiflexion; PF= Plantar flexion.

6. DISCUSSION

This study presents findings that help to discuss about the effectiveness of robotic therapy protocols applied to people with ankle restrictions of movements because neurologic diseases (Forrester et al., 2011; Chang et al., 2017). Previous studies have shown gait performance improvement. These findings can help explain some gains considering ankle joint. The robotic therapy protocol associated with the videogame proved to be efficient in promoting adjustments of ankle sensorimotor control, mainly during dorsiflexion. According to the aim of the study, this study showed short-term effects of a single robotic therapy session by observing the change in sensorimotor control during the submaximal torque maintenance for healthy individuals.

This work showed how important it is to consider firstly a pilot with healthy individuals. Many research groups perform preliminary tests with healthy subjects to verify details about the study protocol, but they do not report this process in the manuscripts to contribute for futures studies (Forrester et al., 2016; Roy et al. 2011). The results of this pilot suggest that the protocol presented could be applied in a pilot study with patients because it was not promoted any adverse effects, that is, it was not present any decrease in the performance observed in both the submaximal force and the game score data. By analyzing the results of the game score was observed that the level of difficulty was appropriate and easy to understand. The motivation level reported was satisfactory, the strategies of impedance variation and feedback were efficient, keeping the number of correct answers in the different blocks. It is important to apply an assessment tool, a questionnaire, which provides information on motivation, attention, discomforts and game reasoning during the protocol.

According to Roy et al. (2011), the gradual impedance wave strategy adopted here was effective in offering motivation and challenges to the players, according to reports from participants. This strategy in addition to the intensity of repetitions showed an improvement in sensorimotor control during dorsiflexion after robotic therapy, which was observed in a steadiness analysis.

Therefore, when proposing a robotic therapy protocol, it is important to establish criteria to determine specific details concerning progression protocol. In addition, the difficulty of the task corresponding to the skill level while performing is an important criterion to prevent frustration, boredom and fatigue when engaging the learner in robotic therapy.

7. CONCLUSION

A brief reflection and important topics for the elaboration of robotic therapy protocols from the data analysis of this pilot study with health subjects was proposed. Regarding the data presented, health individuals presented short-term adaptation in submaximal torque maintenance performance (sensorimotor control) during dorsiflexion after a single robotic therapy session.

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