Integration of the AGoRA exoskeleton and the T-FLEX robotic orthosis

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Abstract

New technologies have been developed in rehabilitation to meet the needs of people and rehabilitate the limb affected by hemiplegia. This study evaluates the integration of a unilateral hip and knee exoskeleton (AGoRA) and a T-FLEX robotic orthosis qualitatively and quantitatively in non-pathological users. Four subjects executed two six-minute walking tests (6MWT) on a treadmill. The first was performed unassisted, and the second was performed using the AGoRA exoskeleton and the T-FLEX orthosis during the activity. The results indicate significant differences when comparing the peaks of muscle activity in the two test modes. In addition, a reduction of muscle activity is found in the BF, GL, and TA for three subjects.

Keywords: Stroke, unilateral exoskeleton, orthosis.

1. Introduction

Stroke is known as the accelerated development of focal signs or global signs of compromised brain function. It is also the most common neurological disease, with a worldwide average incidence of 200 cases per 100,000 inhabitants and a prevalence of 600 cases per 100,000 inhabitants. In Colombia, it occurs in 45,000 inhabitants each year (Chirveche, 2016). Stroke patients present hemiparesis, which refers to complete or partial muscle weakness or paralysis to affect a part of the body and its mobility (Bindawas, 2017). This can affect the person's quality of life by not performing normal activities of daily living. Assistive robots such as exoskeletons can improve these neurophysiologic mechanisms allowing the person to perform activities of daily living with autonomy by rehabilitating/assisting the limb affected by the disease (Shore, 2018).

The AGoRA project, which is based on developing an adaptive platform for rehabilitation and walking assistance, consists of a unilateral AGoRA hip-knee exoskeleton and a robotic-ankle foot orthosis known as T-FLEX. The first one is designed for stroke victims and is considered a rigid structure (Manchola, 2018). The second is the development of soft robotics, and it is designed to treat foot drop. This neuromuscular disease affects the foot's ability to move in the sagittal plane during walking (Manchola, 2019).

This study presents the assessment of the mechatronic integration of the AGoRA exoskeleton and a T-FLEX robotic orthosis by evaluating qualitative and quantitative parameters in non-pathological users. To assess the tests performed, physiological parameters are considered. In addition, to know the level of user satisfaction, a questionnaire is carried out at the end of each test.

2. Development

2.1 Theoretical framework

The T-FLEX orthosis is designed to assist and rehabilitate people with ankle dysfunction. It uses a machine-learning algorithm to estimate the user's gait phases in real-time. In addition, the control strategy assists ankle dorsiflexion (Manchola, 2019). It has been used in a study with ten users with stroke where an improvement in ankle kinematics was found, with significant changes of 70% in the range of motion of the subjects' lower joints. In addition, T-FLEX was found to reduce users' fall risk by positively impacting dorsiflexion motion (Gomez, 2020).

The unilateral AGoRA exoskeleton has three active degrees of freedom (DOF), including the hip and knee joints along the sagittal plane and a passive DOF at the hip joint along the frontal plane, which is essential in lateral balance control (Manchola, 2018). A study evaluates two control strategies in the AGoRA exoskeleton, the transparency mode and the assistance mode. The transparency mode uses an admittance controller that renders torque and force values at angular velocity and a velocity controller. The assistance mode requires an impedance controller that converts position values to force or torque and uses a torque controller (Arciniegas, 2021).

2.2 Problem statement

Based on the results obtained from previous studies with the AGoRA exoskeleton and the T-FLEX orthosis separately, where promising results have been obtained, the integration of the two devices is proposed. The objective is to evaluate the assistance it provides to the person through muscle activity, perception of the exoskeleton’s characteristics, and physical condition. Finally, the results will define a baseline that will serve for future work in patients.

2.3 Method

The assessment of the mechatronic integration of the devices includes four subjects executing two six-minute walking tests (6MWT) at a speed of 1km/h on a treadmill. The first was performed unassisted, and the second was performed using the AGoRA exoskeleton and the T-FLEX orthosis during the activity. In the quantitative part, physiological gait parameters are evaluated. This is achieved using the maximum peaks of the muscle activity envelope in the two conditions. The envelope is performed using the root mean squares (RMS) with a moving window of 300ms, based on averaging the data and serves as an estimator of the signal amplitude behavior (SENIAM, 1999). The envelope peaks are found using the “Findpeaks” function in MATLAB. In the qualitative part, two surveys are conducted at the end of the test, a questionnaire (QUEST) to know the user satisfaction level and a Visual Analogue Scale (VAS) to see the fatigue, pain, and comfortable condition. For the muscle activity evaluation, each muscle’s maximum voluntary contraction (MVC) is performed. The process consists of 10 seconds of relaxation and 5 seconds of maximum contraction, performed three times for each muscle. The resulting value is obtained by averaging the three maximum values of each contraction. For the integration test, four muscles are evaluated: the biceps femoris (BF), lateral gastrocnemius (GL), tibialis anterior (TA), and the vastus lateralis (VL); the MVC is also performed to normalize each person’s muscle activity data. The data were analyzed statistically with the IMB SPSS

Statistics Software using Kolmogorov-Smirnov's normality tests. To compare the muscles in each mode, the Mann-Whitney U Test and the Unpaired T-Test. The p-value<0.05 refers to significant changes in muscle activity.

2.4 Results and discussion

From the peaks of the envelope obtained from each muscle, an analysis is made comparing their amplitude with and without the robotic devices. Table 1 shows the average values and standard deviation of the peaks of the envelope conducted on the EMG signal. This is performed for the two test modes for the four muscles. In the device integration test, significant changes in muscle activity were observed. In Table 1, reduced mean muscle activity is observed: subject 1 for the BF muscle, subjects 3 and 4 for the GL muscle, and subject 3 for the TA muscle. This indicates that the exoskeleton performs the assistance of the limb correctly, causing the person to make a minimum effort when performing the gait activity. These results are consistent with those found in studies conducted with unilateral exoskeletons in non-pathological users. Ankle exoskeletons such as WAXO and WAE and hip exoskeletons such as ALEX II reduce muscle activity in the actuated limb (Bougrinat, 2019) (Lenzi, 2013). However, in some cases, the muscle activity is increased because it can be influenced by the position of the electrodes and the AgoRA exoskeleton supports. Besides, the user is walking with a 17kg exoskeleton, which may force or alter some gait movements. In addition, when comparing the muscles in the two gait modes, significant differences are found in muscle activity in all four muscles (BF, GL, TA, and VL), as seen in Table 2.

Subject	BF		GL		TA		VL	
	WOE	WE	WOE	WE	WOE	WE	WOE	WE
1	8.1±3.4	6.3±2.3	8.6±2.2	9.3±4.4	4.2±1.5	4.9±6.5	7.1±2.1	16.4±6.5
2	0.8±0.4*	1.1±0.4*	5.6±2.7	9.6±5.4	5.3±2.1	7.4±4.2	2.0±0.6	7.4±4.2
3	0.7±0.4*	1.4±0.7*	12.2±5.4*	6.5±3.4*	3.4±1.4*	2.6±6.5*	11.9±3.4	22.1±6.1
4	17.9±5.4	25.8±11.2	3.4±0.9	3.1±0.7	3.9±1.6*	3.9±3.4*	8.5±2.7	13.8±3.4

Table 1. Mean and standard deviation of the peaks of EMG signals. WOE refers to Without exoskeletons and WE with exoskeletons *data with normal distribution. Values highlighted in gray correspond to average muscle activity reduction.

Subject	p-value			
	BF	GL	TA	VL
1	$p<0.001^-$	$p<0.001^+$	$p<0.001^+$	$p<0.001^+$
2	0.050^+	$p<0.001^+$	$p<0.001^+$	0.0200^+
3	$p<0.001^+$	$p<0.001^-$	$p<0.001^-$	0.989^+
4	$p<0.001^+$	$p<0.001^-$	$p<0.001^+$	$p<0.001^+$

Table 2. p-value when comparing the muscles with and without the robotic devices, where values highlighted in gray correspond to significant changes in muscle activity (p<0.05*). Positive symbols at the end of the number refer to increased muscle activity, and negative symbols refer to decreased muscle activity.

Furthermore, a positive response was obtained in the QUEST of user satisfaction in the test of the integration of the exoskeletons. According to Figure 3, the dimensions, safety, effectiveness, and ease of adjusting the devices are the most satisfactory parameters among the four users. At the same time, comfort and weight are the parameters that indicate the least satisfaction. This should be considered for future testing. On the other hand, in the Visual Analogue Scale (VAS), the participants were asked to choose on a scale of 1 to 10 whether they felt highly uncomfortable (U), fatigued (F), or in a considerable amount of pain (P), with 10 being the response.

Or on the other hand, if they felt extremely comfortable, fatigue-free, and pain-free, being one the response. The following results show that users did not experience fatigue and felt most comfortable with the devices. However, the pain experienced may be caused by the system's weight, being a parameter to be solved.

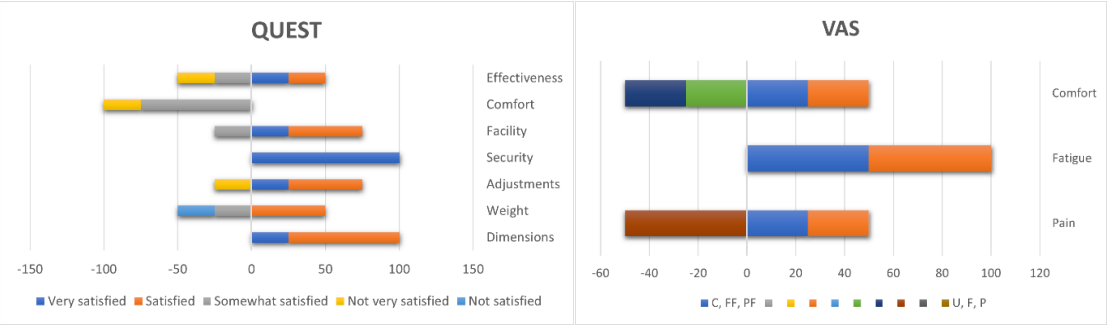

Figure 3. User's perceptions when using the robotic devices. (left) QUEST and (right) VAS.

3. Conclusions

As the main conclusion, a reduction in muscle activity was observed in the four muscles of gait activity, which is also consistent with literature findings; however, the phases of gait for each parameter should be considered in future studies. Users did not experience fatigue during the test; however, it should be regarded as reducing or distributing the weight of the devices for future trials better. In addition, the results obtained indicate a baseline for further comparison in studies of patients with stroke.

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