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Investigation of maximum voluntary contraction activity during robotic gait

Robotik yürüyüş sırasında maksimum istemli kasılma aktivitesinin incelenmesi

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Investigation of Maximum Voluntary Contraction Activity during Robotic Gait

Highlights

- *Gait Analysis*
- *Change of Maximum Voluntary Contraction in Different Groups*
- *Effects of Robotic Walking on Muscles*
- *Human-Robot Interaction*
- *Muscle Gait Interaction*

Graphical Abstract

Signals received from different patients and healthy individuals were analyzed by filtering, rectifying, signal processing techniques such as Root Mean Square (RMS) and calculating Maximum Voluntary Contraction (MVC).

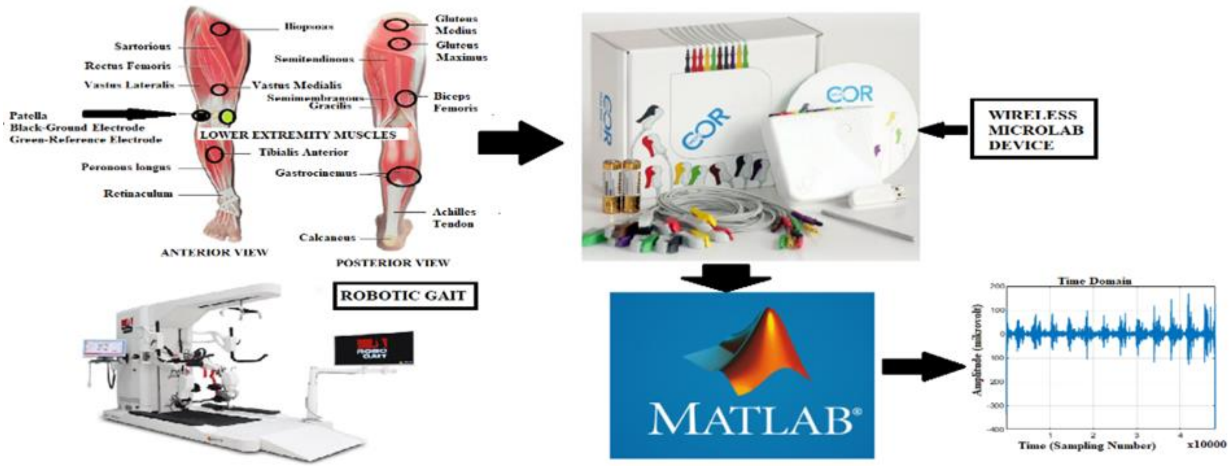

Figure. EMG analysis of lower extremity muscles using robotic gait system

Aim

The purpose of this study is to investigate healthy people's and patients' lower extremity muscle activities during robotic gait using kinesiology analysis.

Design & Methodology

In this study, Maximum Voluntary Contraction and RMS were investigated in different patient groups.

Originality

In this study, MVC and RMS were investigated together for the first time in robotic walking in different patient groups with different electrode placement.

Findings

It was observed that MVC values of hip muscles such as GMA, GM and ILP in hemiplegic patients were lower than those of SCI patients and healthy individuals.

Conclusion

The EMG results of gait motion may be helpful in applying accurate amplitude and frequency stimulation in epidural stimulation (ES) therapy.

Declaration of Ethical Standards

For the participation of patients in this study, the approval of Adana City Hospital Ethics Committee was requested and received on 27.03.2018 from Adana City Hospital (Ethical Protocol No:13-178-27.03.2018).

Robotik Yürüyüş Sırasında Maksimum İstemli Kasılma Aktivitesinin İncelenmesi

Araştırma Makalesi / Research Article

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ÖZ

Bu çalışmanın amacı, sağlıklı kişilerin ve hastaların robotik yürüyüş sırasında alt ekstremite kas aktivitelerini kinesiyoloji analizi kullanarak incelemektir. Başlangıçta spinal cord injury (SCI) ve inme hastaları gibi 6 paraplejik hastadan, 2 hemiplejik hastadan ve 4 sağlıklı kişiden kas sinyalleri alındı. Ardından, filtreleme, doğrultma, Ortalama Karekök (RMS) gibi sinyal işleme teknikleri kullanılarak ve ayrıca Maksimum Gönüllü Kasılma (MVC) hesaplanarak sinyaller analiz edilmiştir. Sonuç olarak hemiplejik hastalarda Gluteus Maximus (GMA), Gluteus Medius (GM) ve Iliopsoas (ILP) gibi kalça kaslarının MVC değerlerinin SCI hastalarına ve sağlıklı kişilere göre daha düşük olduğu görüldü. Ayrıca elde edilen sinyaller analiz edildiğinde Medial Gastrocnemius (MG) kasının aktivitesinin hareket yolunun ve hareket niyetinin belirlenmesinde kullanılabileceği bulundu. Ayrıca, yürüyüş hareketinin EMG sonuçları, epidural stimülasyon (ES) tedavisinde doğru genlik ve frekans stimülasyonunun uygulanmasında yardımcı olabilir.

Anahtar Kelimeler: EMG, MVC, yürüme analizi, dış iskelet, kinezyoloji.

Investigation of Maximum Voluntary Contraction Activity during Robotic Gait

ABSTRACT

The purpose of this study is to investigate healthy people's and patients' lower extremity muscle activities during robotic gait using kinesiology analysis. Initially, muscle signals were taken from 6 paraplegic patients such as spinal cord injury (SCI) and stroke patients, 2 hemiplegic patients and 4 healthy persons. Then, signals were analyzed by using signal processing techniques such as filtering, rectifying, Root Mean Square (RMS) and also by calculating the Max Voluntary Contraction (MVC). As a result, it was seen that hip muscles such as the Gluteus Maximus (GMA), Gluteus Medius (GM) and Iliopsoas (ILP) had lower MVC values in the hemiplegic patients than those of the SCI patients and the healthy persons. Additionally, when the signals that were obtained were analyzed, it was found that the activity of the Medial Gastrocnemius (MG) muscle could be used in determination of movement path and movement intention. Moreover, the EMG results of gait motion may be helpful in applying accurate amplitude and frequency stimulation in epidural stimulation (ES) therapy.

Keywords: EMG, MVC, gait analysis, exoskeleton, kinesiology.

1. INTRODUCTION

In the Physical Treatment and Rehabilitation process (PTR), application of gait training programs have shown to be effective on regaining gait ability in many neurological diseases such as Stroke, SCI and others [1, 2]. Hence, people with neurological diseases require PTR processes and gait training programs in order to recover and sustain a healthy life style [3]. With the use of robotic technology in physical therapy, conventional methods applied in robotic gait training have come to the point of effective robot-assisted treatments. [4]. The aim of robotic gait training programs is to strengthen weak and apathetic muscles while assisting in healing of the nervous system by inducing neuronal activity [5].

Lokomat and RoboGait robotic devices, which measures patient weight by a lifter, are used at clinical and physical treatment centers in robotic assisted treatments [6, 7]. These devices improve muscle and neural activity of the patient by facilitating controlled physical activities which include controlled abduction, adduction and flexion movements at determined angle and speed device that is developed to perform functions of human gait ability. In RLEE design, Human-Robot interaction plays an important role for determining the design parameters [8]. Electromyogram (EMG) and kinesiology methods are used for analyzing Human-robot interactions. In the literature, most studies are focused on the analysis of gait ability in order to provide accurate gait planning. EMG is used to determination gait intention as control input for controlling of exoskeleton and calculate the joints motor power in the exoskeleton [9]. More than 200 muscles including Vastus Medialis (VM), Biceps Femoris (BF), Rectus Femoris (RF), Tibialis Anterior (TA), Medial

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Gastrocnemius (MG), Soleus (SOL), Gluteus Medius (GME), Gluteus Maximus (GMA), Iliopsoas (ILP), Lateral Gastrocnemius (LG) and others are active during gait [10]. Lee et al. (2016) analyzed the EMG activity of lower extremity muscles such as RF, BF, TA, SOL and LG during pedaling and ground gaiting. Their study with 15 participants included analyzing EMG signals as 20 seconds recordings. Their results showed that there was a significant increase in the use of double-sided RF in Pedalo Reha-Bar pedaling, as well as a significant decrease in left TA and left use in Pedalo Reha-Bar pedaling [11]. Nor M. N. M et al. (2019) analyzed EMG signals from BF and RF during gaiting and concluded the importance of using the RF muscle in rehabilitation process. Most of these studies are generally performed with active and passive amplification electrodes in healthy people [12]. In some limited studies conducted by Androwis G. J. et al. (2018), only six leg muscles' signals' effects on gaiting were examined by using the Burst Duration Similarity Index (BDSI) method. It was observed that voluntary muscle contraction occurs in affected and unaffected limbs despite different muscle activation levels [11]. Recently, electrotherapy studies have examined the effects of transmitting signals from the brain to the legs with epidural stimulation (ES). ES is an application based on the technique of placing a durometer on the posterior surface of the spinal cord, where it will apply an electric current for certain periods of time to be transmitted to the electrode. With this technique, it is aimed to strengthen the nerve signals originating from the brain and direct them to the spinal cord tissue below the injury level. Thus, it is ensured that voluntary movements are regained and lost functions are regained. The study conducted by Mesbah S. et al. (2018) investigated the spectral content of EMG signals recorded during spinal cord epidural stimulation (ES) in patients with motor SCI. It was predicted that the spectral intensity of EMG may help adjust the stimulation parameters to achieve an independent posture in individuals with SCI [13]. Another area of study is spinal cord stimulation (SCS) which has enabled individuals with motor SCI activity to recover some autonomic functions. However, the interaction between SCS and motor activity training is not clear. For this purpose, the correlation between SCI patients' motor activity and general standing ability compared to healthy individuals was investigated. In Yue C. et al. (2018) studies, it has been showed that neuronal activity of SCI patients was different than muscle activity of healthy individuals during training on standing balance. Although the patients' training on standing balance increased motor activation patterns, it did not improve their standing ability. These results showed that current robotic therapy techniques do not affect motor activity at the optimum level. Therefore, it has been suggested that robot-assisted rehabilitation strategies for SCI patients should target individualized motor activity rather than mimic healthy muscle activity to optimize functional performance [14-16].

In this study, EMG data was collected and analyzed from 6 paraplegic, 2 hemiplegic and 4 healthy people with lower extremity disability. The aim is to provide the planning of gait training by comparing the obtained EMG data in healthy people with lower extremity problems.

2. MATERIAL and METHOD

Gait analysis is known as analysis of movement. A gait cycle is defined as the time elapsed between the same heel hitting the ground on the right or left leg [17]. The human gait cycle is divided into two separate phases that represents the period of time when one-foot is in contact or not in contact with the ground. These are the phase of Stance (R), indicating the period when the limb is in contact, and the Swing (S) phase when the limb is not in contact with the ground. During the Stance phase, the body's mass is supported by the contact of one-foot with the ground, and the body is shifted forwards in the following stance phase. The Stance (R) phase Figure 1 shows the initial contact, loading response, midstance, terminal stance and pre-swing vertical ground reaction force (vGRF) occurrences during the stance phase (R) in the gait cycle. Another part of gait is the swing phase which the reference foot is not in contact with the ground and swings in the air. The swing phase consist of three phases such as initial, mid and terminal-swing [18].

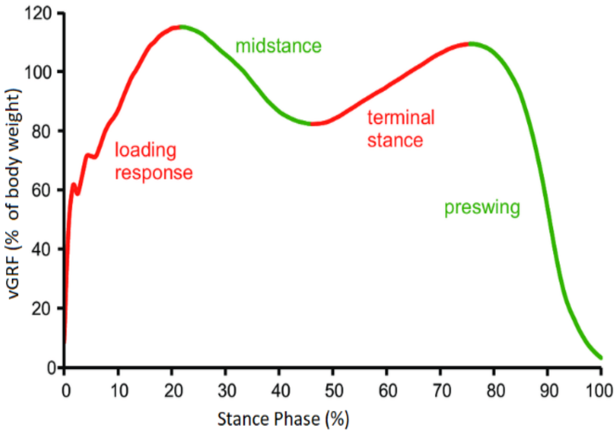


Figure 1. VGRF during stance phase in normal human gait cycle [19]

2.1 Electrode Placement and EMG Measurement

In this study, the EMG activity of 7 major muscle groups that play an essential role in the movement of hip, knee and ankle joints and are vital in human gait will be examined. In the hip, GMA, Iliopsoas and GME muscles are involved in hip extension, hip flexion and formation of the abduction movement of the hip, respectively. In the knee, VM muscle is involved in knee extension, and BF muscle is involved in knee flexion. As for the ankle, TA muscle is involved in the movement of dorsiflexion, while MG muscle is involved in formation of foot plantar flexion.

A MicroCor Lab Device was used for recording lower extremity muscles' signals. MicroCor Lab is a Matlab-based hardware interactive interface developed for the wireless transmission and analysis of low amplitude biological signals to a computer in a laboratory environment. With the wireless data collection unit, the device can sample up to 8 channels of data and perform real-time wireless data transfer to the computer. This device has the appropriate infrastructure for receiving and processing EEG, ECG and EMG physiological signals [19]. Unlike other studies, the electrode placement of the MicroCor device was carried out using a single active and passive amplification electrode. Thus, 7 different EMG signals could be recorded and evaluated simultaneously [20]. The placement of the surface electrodes to the lower extremity muscles and the MicroCor device are shown in Figure 2.

The EMG signals were obtained by using the MicroCor device in raw form with the software prepared on MATLAB 2009ra. The signals were sampled in 8800 Hz and recorded in 550 Hz. Then, the signals were cleared by passing through a bandpass filter with 60 Hz-150 Hz which is the dominant energy interval of EMG signal.

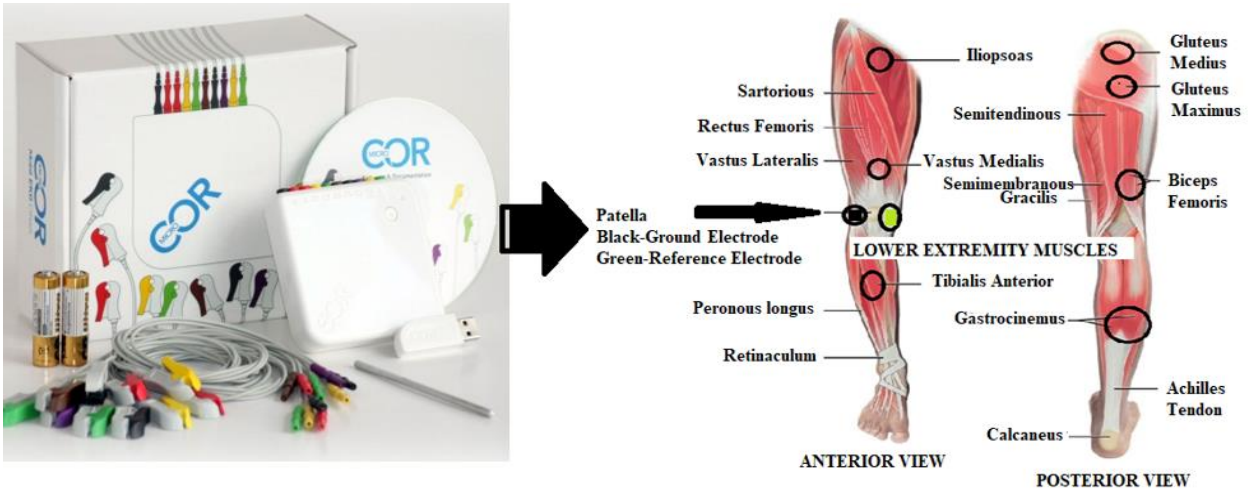


Figure 2. . MicroCor Lab Device and connections

2.2 Measuring System

In this study, the muscle activation potentials of 7 different muscle groups of the patient with dysfunction in the lower extremities were transferred to the computer simultaneously during their gait cycle on the RoboGait device. Robot Assisted Gait Therapy In cases of loss of walking ability due to traumatic brain and spinal cord injuries, stroke, neurological or orthopedic reasons, RoboGait® is a robot-assisted gait rehabilitation system used for regaining and improving walking ability. The basic approach in the treatment is to mobilize the dysfunctional lower extremities in a normal gait pattern and to perform the load transfer in a controlled manner. RoboGait is aimed at redefining gait in the brain by activating the locomotive system. A combined treatment is targeted by activating the neuronal pathway with the gait formed under the control of the robotic system [22]. The EMG signals of 7 lower extremity muscles were collected by using MicroCor Lab device during robot assisted gait training with the attachment of surface electrodes the patients. The block diagram of the established EMG analysis system of lower extremity muscle groups is given in Figure 3.

The Bandpass Matlab function was used to filter the 60-150 Hz frequency range, which is the most dominant range of voluntary muscle movements in the EMG signal.

The MVC value was calculated after the filtering process. This post-processing method is based on the maximum EMG value recorded for 5 minutes and it also evaluates the 45000 EMG data samples (about 80 seconds) according to RMS. The result is displayed as a percentage of the MVC value (MVC%). The mathematical formulation of the RMS value is given below in Equation 1:

$$\boldsymbol{X_{RMS}} = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + x_3^2 + \cdots + x_n^2} \ldots \qquad (1)$$

The post-processing method provides a common control data in comparing the data among the people who are recorded. According to Meldrum et al (2015). EMG signals have a user-based nature. Therefore, each patient will have different EMG signals in the recordings even when the measurements are taken at the same location with the same motion and experimental setup [21]. MVC normalization eliminates this variance and allows inter-individual data comparison [22, 23]. To find the MVC value, after filtering the signals, the absolute value was taken with the Abs command to rectify the signals. After rectification, MATLAB's envelope function based on Hilbert transform was used to obtain the RMS envelope [24].

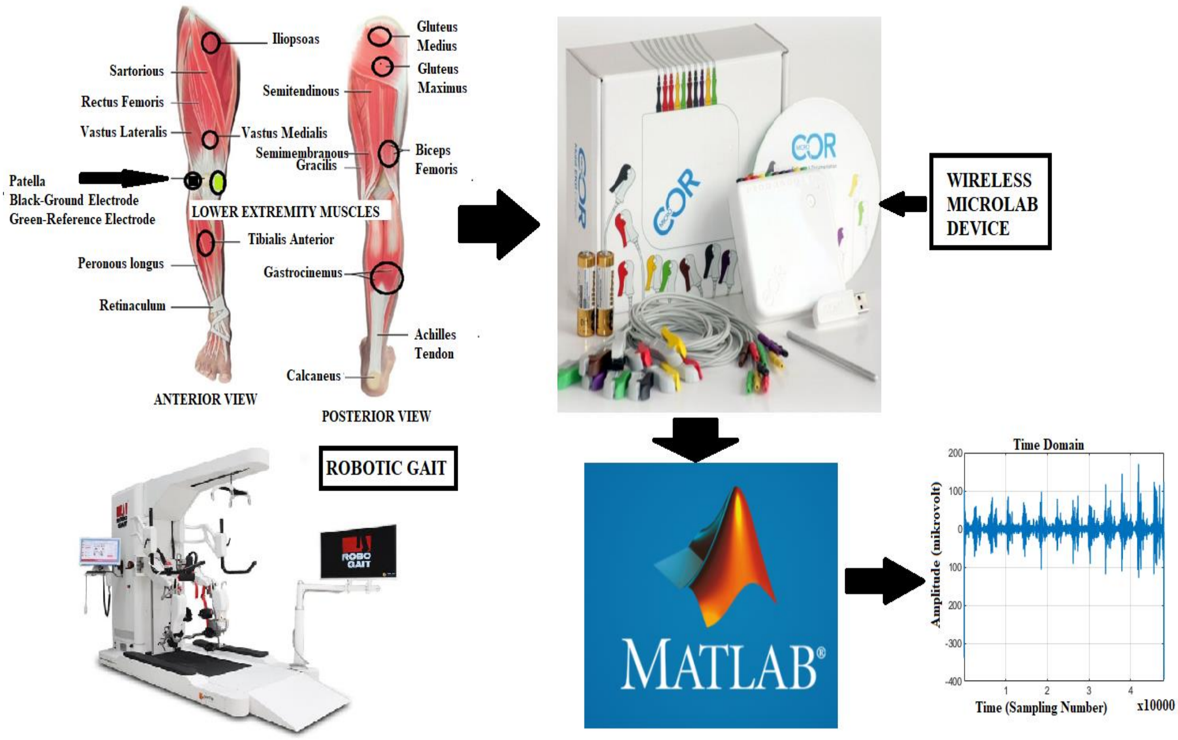


Figure 3. EMG analysis of lower extremity muscles using robotic gait system

2.3 Participants

A total of 12 participants, consist of 6 paraplegic, 2 hemiplegic and 4 healthy individuals, were included in this study. EMG signals of the paraplegic, hemiplegic patients and healthy individuals were recorded for 5 minutes during their gait training on the RoboGait lower extremity robot. The patients disease type and location as well as the causes are presented in Table 1. The patients were between the ages of 17 and 60 and had a mean age of 32.5±13.5 years. The healthy participants had a mean age of 32 ± 3.91 years and were between the age range of 27-37 years. The experimental procedure involved providing information to the participants about the study and design of the study which was followed by patients signing a written consent. For the participation of patients in this study, the approval of Adana City Hospital Ethics Committee was requested and received on 27.03.2018 from Adana City Hospital (Ethical Protocol No:13-178-27.03.2018).

Table 1. Information of participating patients

Participants	Disease Type	Cause	Disease Location
Patient 1-P1	Hemiplegic	Ischemic cerebrovascular disease	Left motor cortex
Patient 2-P2	Hemiplegic	Ischemic cerebrovascular disease	Left motor cortex
Patient 3-P3	Paraplegic	Traffic accident	T8 SCI
Patient 4-P4	Paraplegic	Falling from high	T10 SCI
Patient 5-P5	Paraplegic	Traffic Accident	T6 SCI
Patient 6-P6	Paraplegic	Tumor in Spinal Cord	T6 SCI
Patient 7-P7	Paraplegic	Traffic Accident	T8 SCI
Patient 8-P8	Paraplegic	Falling from High	T10 SCI

3. RESULTS

In this study, EMG signals from 6 paraplegic, 2 hemiplegic patients and 4 healthy subjects with lower extremity problems were recorded for 5 minutes during robotic gait training on the RoboGait lower extremity robot.

3.1. EMG signals of paraplegic patients

The EMG signals generated by the GMA, GME, ILP, VM, TA, BF and GM muscles, which are active during gait training, of 6 paraplegic and 2 hemiplegic patients with lower extremities muscle problems were recorded and transferred to the MATLAB software by the

MicroCor Lab device. During the EMG signal measurement, orientation of the single reference electrode and return (ground) electrode is given in Figure 2 which were attached onto the kneecap (patella) in order to prevent phase shifting and allow simultaneous collection of the generated EMG signals. Figure 4 shows the EMG signals of patient 3 (P3) with incomplete SCI at T8. The signals were measured with a single reference and 7 return (ground) electrodes. The measured EMG signals were obtained by a bandpass filter operating at passband filter frequency between 60 and 150 Hz. Although the measured signals were on the same axis, an offset voltage of 1000μV was added to each channel to make it easier to see the changes in the signals.

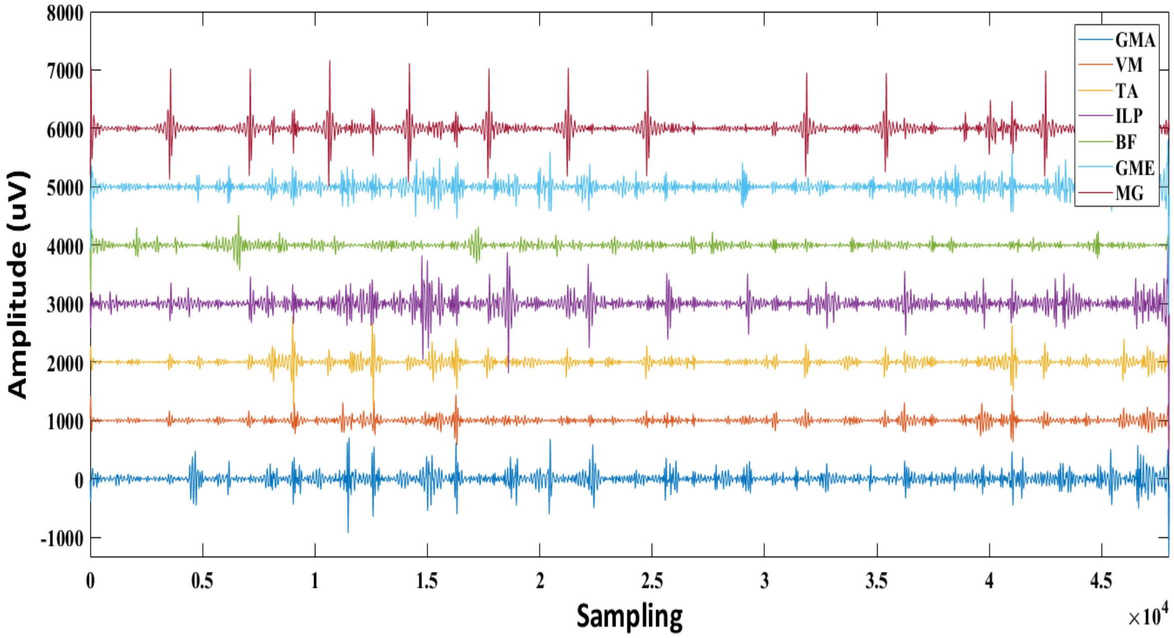


Figure 4. Paraplegic EMG signals of a patient (Patient 3)

When the EMG signals of the patient with lower extremity muscle problems were examined, it was observed that the gait disability and the place of spinal cord injury had destructive effects on the amplitude of EMG signals generated as well as in the duration and frequency of muscle contraction. The reason for this was thought to be the inability of muscles to contract as a result of atrophy in some patients due to their spinal cord injury location. An example of this would be the EMG signals of a patient with a complete incision in the spine at T6. When compared, patient 6 (P6) had lower amplitude of EMG signals generated, Figure 5, than patient 3 on lower extremity muscles, indicating their physical inactivity even during robot assisted gait.

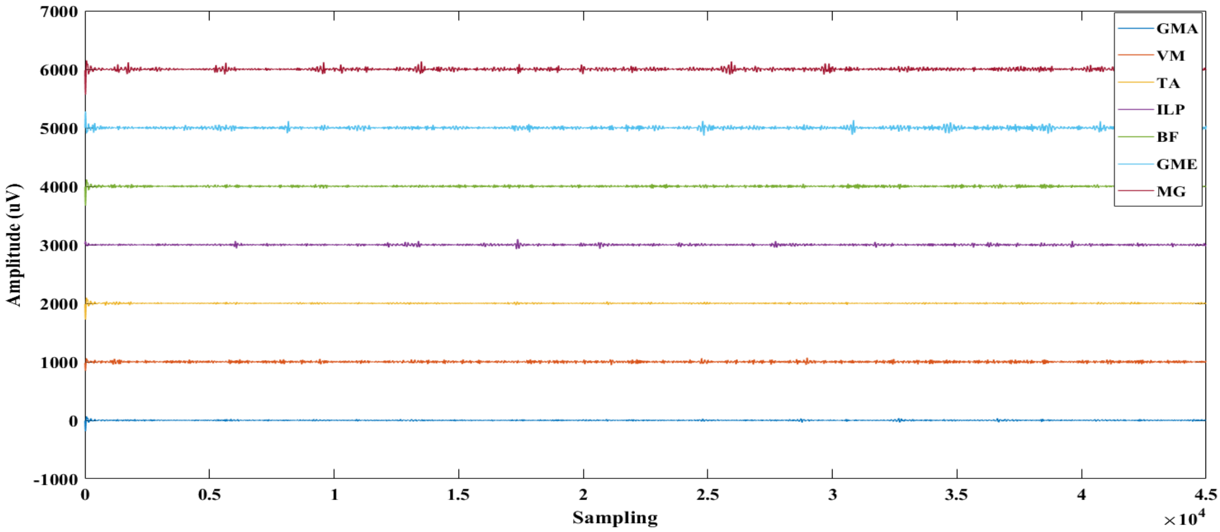


Figure 5. EMG signals with complete incision SCI (Patient 6)

3.2. EMG signals of hemiplegic patients

Muscle weakness, spasticity, abnormal synergistic activation and interactions are mechanical consequences of most hemiplegic gait disorders. Considering the role of diminished neuronal pathways of the brain stem in body support, locomotion and post-stroke spasticity, robot assisted gait training has beneficial consequences such as strengthening muscles and activating neuronal pathways. The EMG signals of hemiplegic patient (P5) are given in Figure 6.

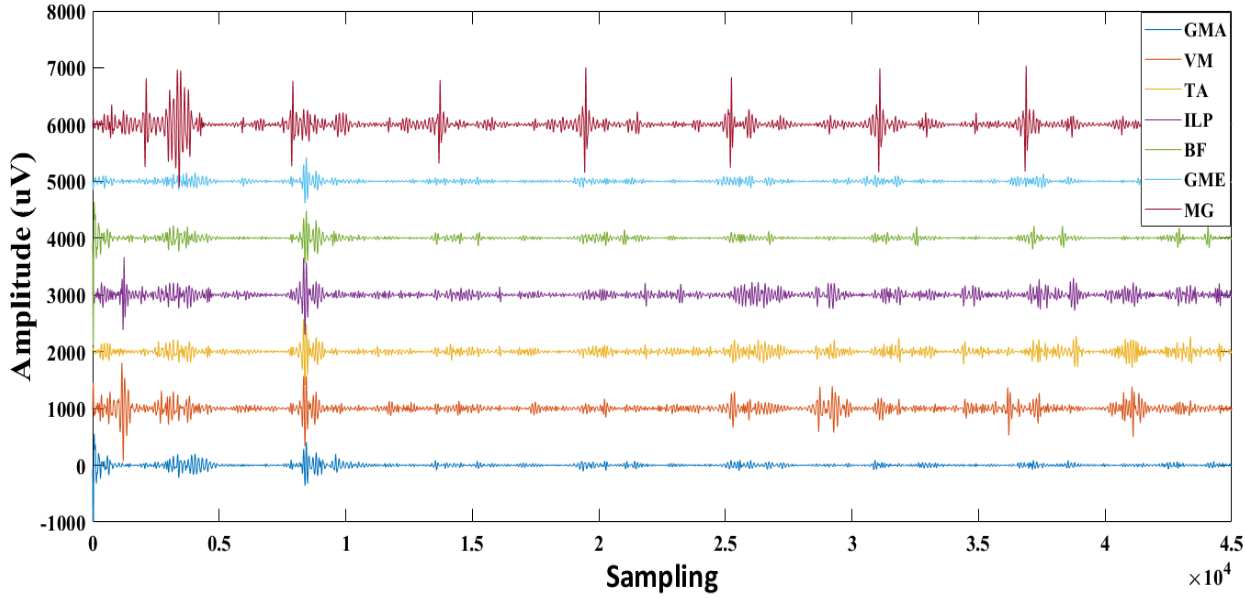


Figure 6. EMG signals of a hemiplegic patient (Patient 5)

3.3. EMG Signals of Healthy People

Figure 7 shows the EMG signals obtained from the healthy participants. It was seen that the EMG signals that were obtained had less amplitude and more contractions. Here, it was thought that the muscles contracted more in a healthy person and reduced the torque to the joints. This revealed how important energy saving is in exoskeleton design.

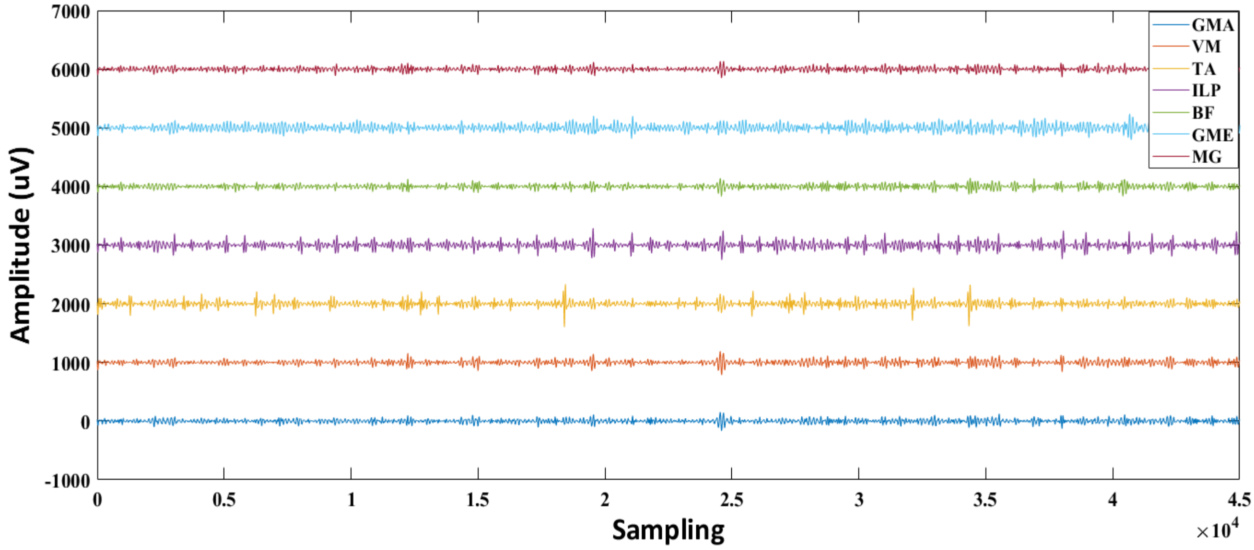


Figure 7. EMG signal of a healthy person

3.4. Evaluation of Muscle Signals During Gait

The signals received from patients and healthy participants were first filtered through passband frequency band of 60-150 Hz in MATLAB. After signal processing, the signals related to the activity of each muscle was passed through the rectification process. The output signals that occurred after the rectification process are given in Figure 8.

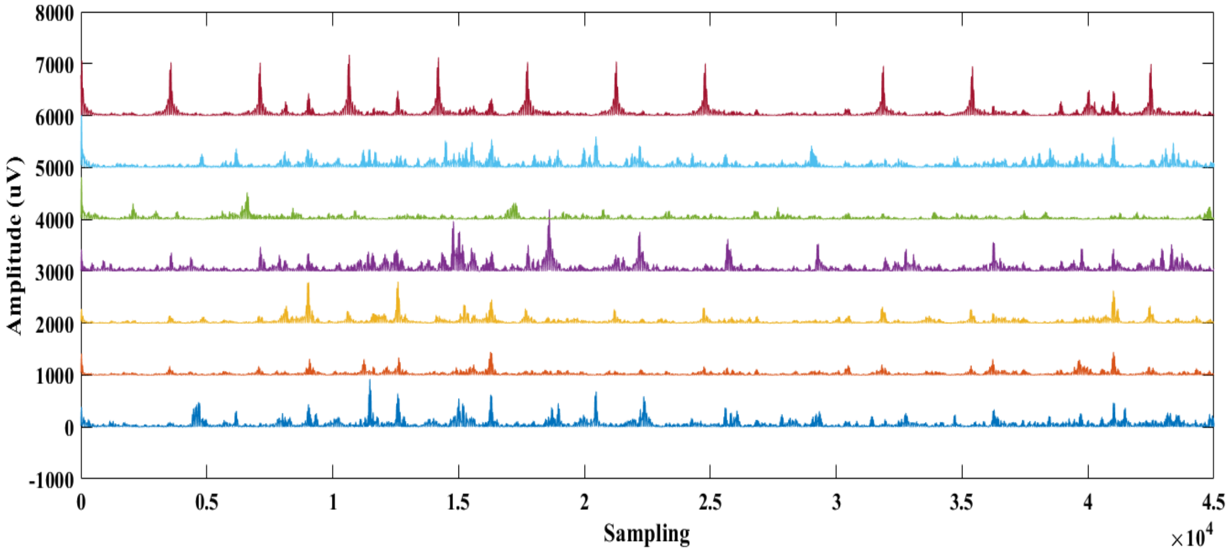
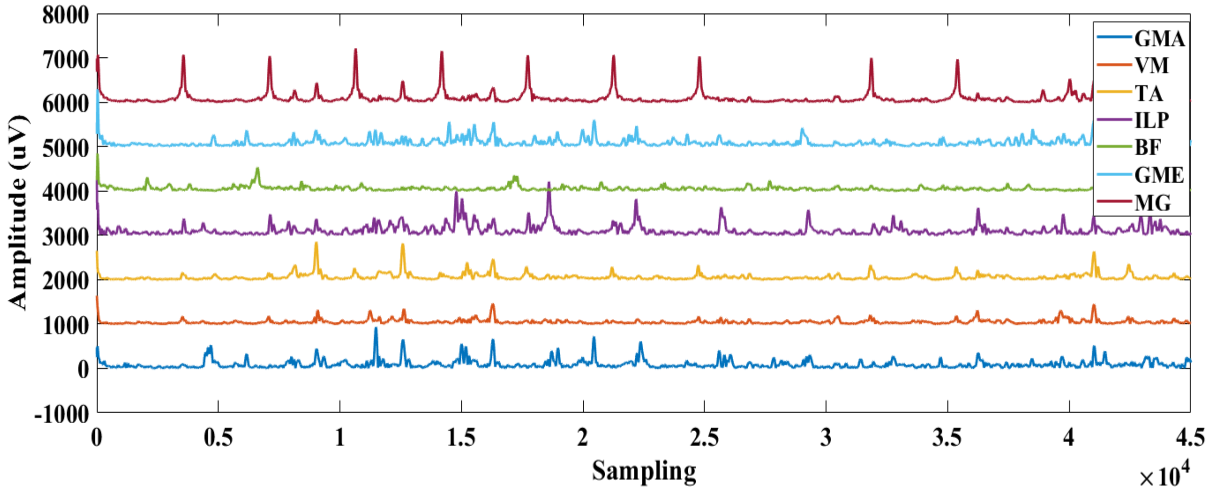


Figure 8. EMG signals as a result of the rectifying process

Following the rectification process, the signals were subjected to RMS envelope processing and the results are shown in Figure 9.



The sequence of which muscles are functioning in terms of the duration of muscle activity can be seen in Figure 9. The measured MVC value, one of the most important measurement systems in muscle examinations, was obtained by using the RMS value of the rectified signal. The MVC values of the patients are given in Table 2, and those for the healthy participants are shown in Table 3.

Table 2. MVC (µV) values for 7 lower extremity muscles of Paraplegic and Hemiplegic patients

Muscle	P1 (µV)	P2 (µV)	P3 (µV)	P4 (µV)	P5 (µV)	P6 (µV)	P7 (µV)	P8 (µV)
GMA	106.2	105.3	7.8	0.0	58.1	22.5	10.4	43.4
GME	107.3	106.2	62.0	88.3	18.1	15.9	11.7	44.9
ILP	75.5	74.1	10.1	90.5	41.7	64.0	0.0	23.6
BF	135.6	135.6	45.0	74.5	46.4	40.3	11.3	44.9
VM	59.3	57.4	16.7	75.1	26.7	16.5	15.1	0.0
MG	129.5	126.5	100.7	126.0	71.2	57.8	19.8	55.7
TA	55.4	54.2	40.6	76.1	25.4	25.4	0.0	22.9

Table 2. MVC (μV) values for 7 lower extremity muscles of healthy individuals

Muscle	H1 (μV)	H2 (μV)	H3 (μV)	H4 (μV)
GMA	33.0	37.1	34.7	19.8
GME	93.4	81.6	38.4	22.2
ILP	116.3	51.8	48.4	24.05
BF	113.9	53.9	54.6	13.2
VM	93.1	52.6	33.3	18.1
MG	52.8	56.9	54.0	16.2
TA	42.3	39.7	33.5	16.4

4. DISCUSSION

In recent years, Robotic or robot assisted therapy is a physical treatment method that is frequently used in the rehabilitation of patients with lower extremity problems resulting from stroke, SCI, etc. EMG is the most useful method for testing human-robot interaction and muscle activity during robotic gait in gait rehabilitation robots. Neurologists use EMG analysis to test the control and reflex mechanisms and to identify synergistic patterns as well as determining the integrity of neural pathways.

When studies on EMG analysis are examined, it is seen that different reference and active electrodes were used for measurement [27, 28]. This results in a time delay called phase shift in muscle signals. In this study, phase shifts on the signals were prevented by using a single reference and 7 return (ground) electrodes, and the EMG signals were synchronized with each other simultaneously. In a study by George L. S. et al. (2018), normalization and high-pass filtering of 40Hz cutting frequency was applied to determine the differences in muscle functions during gait training [29]. In this study, the cutting frequency of the high pass filter was taken as 60 Hz, since it eliminates the impact of the city grid, and the dominant frequency range of EMG is 60-150Hz. In order to avoid the negative effects of the normalization process on EMG, the signal was rectified, and the RMS values were collected [30]. Almost all of the studies were carried out on healthy people and in a normal gait pattern [31-33]. In this study, unlike others, the EMG signals of both healthy individuals and patients were examined on a RoboGait device during gait training.

When the EMG signals were examined, it was seen that each of the 7 muscles examined was in effect and active during gait, and that multiple muscles cooperated in each phase of gaiting. During gait, the MVC values of the patients and healthy individuals were examined, and when the data is analyzed, it is seen that the hemiplegic patients had higher MVC values than the paraplegic SCI patients. Despite robot assisted gait training in patients with SCI, no contraction was observed in some of the 7 lower extremity muscles. The reason for this was believed to be atrophication of the unused muscles, hence losing their function. When the MVC values of the healthy individuals were examined, the MVC values were lower in the muscles involved in the hip movements, while being higher in the other muscles involved in joint movements. The reason for this was thought to be associated with the signals received from the brain of hemiplegic people cause a lot of contraction in the muscles.

In terms of gait, it was found that the MG muscle could be used to start and determine the movement, and motion intention. Additionally, it was thought that the movement can be used to provide correct amplitude and frequency stimulation in epidural stimulation by analyzing the EMG results in paralyzed and healthy people. Although the patients' pathological conditions varied, it was observed that the hips healed the fastest, and thus, long gait orthoses could be used in patient treatment. For this reason, when the EMG signals of the 7 muscles in the hip and lower extremities were examined, the GMA, GME and ILP contraction amplitudes were stronger in the patients, while the MVC values were lower in the SCI patients.

5. CONCLUSIONS

In this study, the activities of muscles, which are the main element of human-robot interaction, were examined during robotic gait. From the analysis of results, it was observed that the GMA, GME and ILP muscles, which are associated with spinal cord injury in patients and movement of the hip in healthy people, had low MVC values, while the hemiplegic patients had higher MVC values. It is believed that this was due to the fact that the signals received from the brain of semi-paralyzed people result in increased contraction in the lower extremity muscles. In paraplegic patients such as SCI, MVC values are almost similar to that of healthy people. Additionally, it has been seen that the MG muscle can be used to start and determine movement.

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DECLARATION OF ETHICAL STANDARDS

For the participation of patients in this study, the approval of Adana City Hospital Ethics Committee was requested and received on 27.03.2018 from Adana City Hospital (Ethical Protocol No:13-178-27.03.2018).

AUTHORS' CONTRIBUTIONS

Uğur FİDAN: Performed the writing of the article and the analysis of the data

İsmail ÇALIKUŞU: Performed the carry out data collection, analysis and article writing.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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