APARATURA
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TransforMe – exoskeleton for gait rehabilitation

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ABSTRACT:

Stroke and neurological disorders significantly affect thousands of individuals annually, leading to considerable physical impairment and functional disability. Gait is one of the most important activities of daily living affected in stroke survivors. Recent technological developments in powered mechatronics solutions can create powerful adjunctive tools/exoskeleton for rehabilitation and potentially accelerate functional recovery. This paper proposes a new lower limb exoskeleton (TransforMe with EMG control) for functional rehabilitation in persons with neurological pathologies. Moreover, there has been presented the main elements of hardware/software system.

TransforMe – egzoszkielet do rehabilitacji chodu

Słowa kluczowe: mechatronika, roboty wspomagające chód, egzoszkielety

STRESZCZENIE:

Niesprawności ruchowe dotyczą coraz większej liczby osób. Są one spowodowane wadami wrodzonymi, chorobami oraz wypadkami. Dla usprawnienia procesu rehabilitacji opracowano wiele urządzeń wspomagających. W artykule opisano projekt wraz z wykonanym prototypem urządzenia do wspomagania chodu TransforMe. Opracowany egzoszkielet jest mobilnym rozwiązaniem wspomagającym realizację podstawowych funkcji, jak: siadanie, wstawanie, chodzenie, wchodzenie i schodzenie ze schodów. Urządzenie jest sterowane za pomocą sygnałów EMG sczytywanych z kończyn dolnych pacjenta. Zaprojektowane rozwiązanie charakteryzuje się modułowością, która umożliwia dostosowanie egzoszkieletu do oczekiwań przyszłych użytkowników.

1. INTRODUCTION

Stroke and neurological disorders are the main cause of serious long-term disability worldwide [1]. Gait is one of the most important activities affected in stroke survivors. In Poland alone, about 400,000 people live with permanent consequences of stroke [2, 3]. In United States alone, about 800,000 people have a new or recurrent stroke every year [4] and most stroke victims experience significant sensory-motor impairments and require rehabilitation to achieve functional independence. In this context, hemiparesis is a manifestation of stroke that affects the contralesional side of the body, and commonly impacts gait [5, 6]. Recovery of movement and motor control in the lower limb has been achieved thanks to rehabilitation [7-11]. Rehabilitation is a major part of patient care. Rehabilitation is the process of re-learning movement. Very often, the problem with proper functioning of the lower limb lies far beyond the limb – in the brain. Rehabilitation rebuilds these motor patterns which were damaged during illness or in accidents. The basis of this process is plasticity and regeneration of the nervous system [12-15]. Treatment is a long process, requiring high regularity [16, 17].

The process of communication between the brain and limb with a sudden uprising of stroke can be represented as a metaphor – a river. This flow is suddenly interrupted by the appearance of a large stone. This stone is stroke. It causes obstruction of flow and partial occurrence of water from the river. In contrast, the process of rehabilitation can be treated as an attempt to rebuild the old riverbed or create a new riverbed. The degree of the reconstruction of this old riverbed (return to health e.g. proper communication or gait) depends primarily on the extent to which stone (stroke) can be flood, break down or remove (rehabilitation) (Fig. 1) [18].

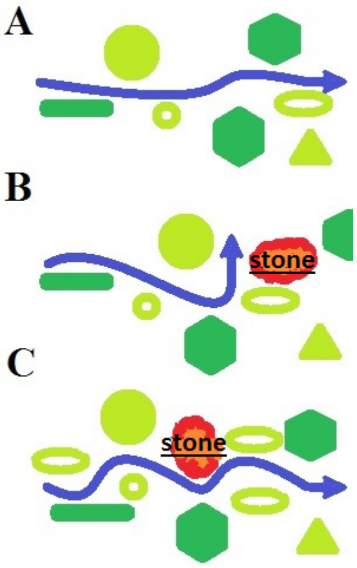

Figure 1 The metaphor of the rehabilitation process represented by the rivers: properly functioning communication brain – lower limb (A), stroke interrupts this communication (B), communication after the rehabilitation process (C) [18]

2. DESIGN OF THE EXOSKELETON

The aim of the project was to develop and make a prototype of a small, portable exoskeleton – "TransforMe". This exoskeleton helps users to get up from chair and walk. The exoskeleton was designed for people who have problem with movement (e.g. they have too weak lower limb muscles or they have problem with communication between brain and lower limb). Element supporting the process of rehabilitation is use of electromyography (EMG signals) in order to stimulate the process of reconstruction by the use of biofeedback. The most important objectives of this project include: lightweight construction, battery power supply, adjustable length of the device, EMG sensors to control the device, mobility and the low cost of the prototype. According to assumptions of low budget for this project, the rapid prototyping method was used to print some parts of this device.

This exoskeleton consists of two parts, each of them was designed for separate lower limb and has one degree of freedom in the knee joint but in this paper we present only exoskeleton for one lower limb because stroke survivors have only problem with one lower limb. The first element of knee joint is connected to the spline with the main wheel of the gear. The second element is the joint and attached gear of the motor. This solution provides the axial stability of the transmission. The gear with ball bearing consists of three large gear and three small gears. There were also applied silent bearings, that provide quiet operation with a low coefficient of friction. This solution has sensors that limit the angle of the motion device. It is associated with anthropometry of lower limb and range of motion in knee joint. A CAD model of this device was designed in the SolidWorks 2014 software (Fig. 2).

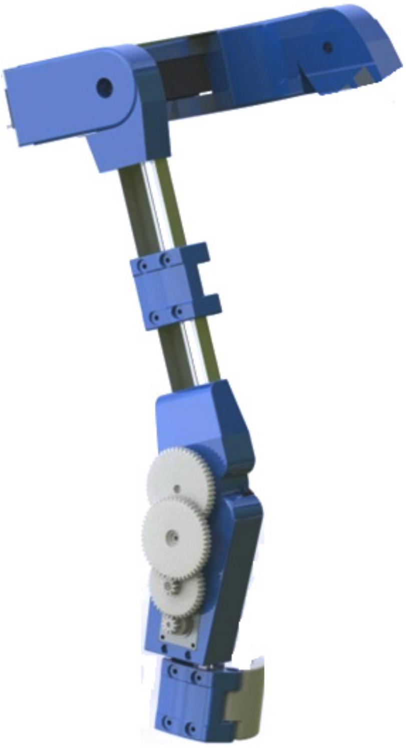

Figure 2 TransforMe – CAD model

The frame was made of a 2 mm aluminium construction. This solution was designed to make the use of device more comfortable. A specialized belt attached to a pelvis was used to fasten the exoskeleton to user's body. An electronics module with the power system was placed on back side of the belt of the pelvis. (Fig. 3a). Exoskeleton will be properly assist the movement, when it is securely attached to the user's body. TransforMe has two mountings: for thigh and for shank (Fig. 3b). The exoskeleton weighs about 6 kg per leg.

3. CONSTRUCTION OF THE EXOSKELETON

This project was based on Arduino Mega, potentiometer, battery, stepper motor, stepstick sensor EMG Advanced Technologies, limit switches. Figure 4 shows the scheme of this device.
To provide adequate support for the process of rehabilitation is use of electromyography (EMG signals) in order to stimulate the process of reconstruction by the use of biofeedback. The system must try to recognize the intentions of the user to make the intended movement. These intentions will be recognized based on the EMG signal. During measurements analog signal is obtained, which can be captured by any microcontroller with analog-digital converter, e.g. Arduino. These sensors require a biomedical electrodes.

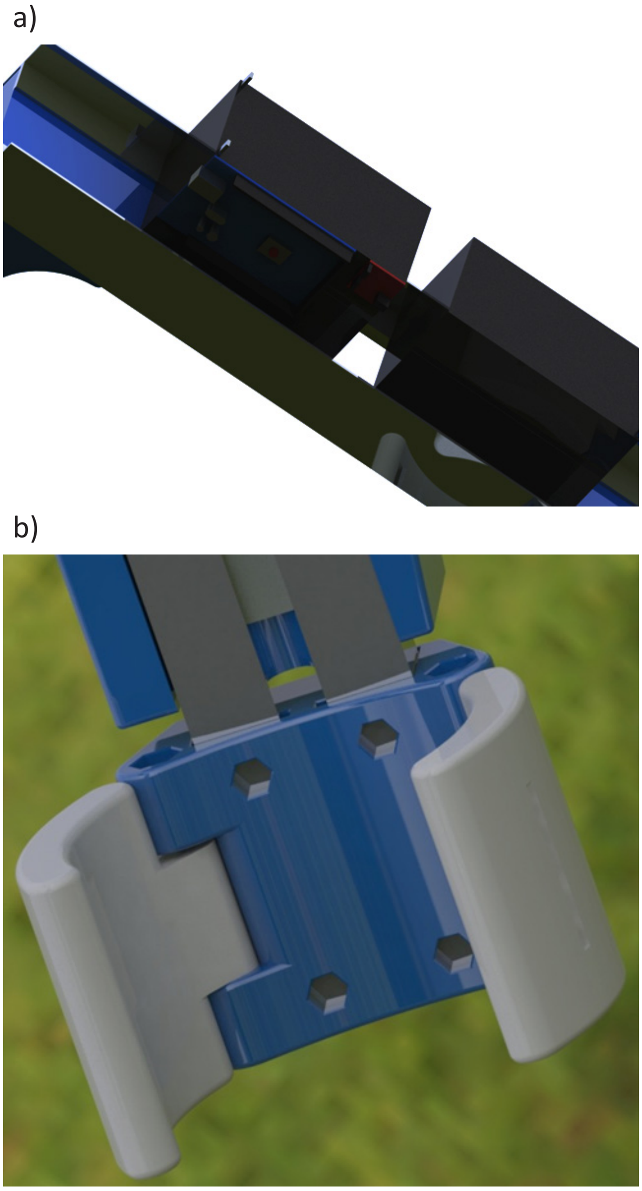

Figure 3 TransforMe – electronics module with the power system on back side of the belt of the pelvis (a) and the mountings for thigh (b)

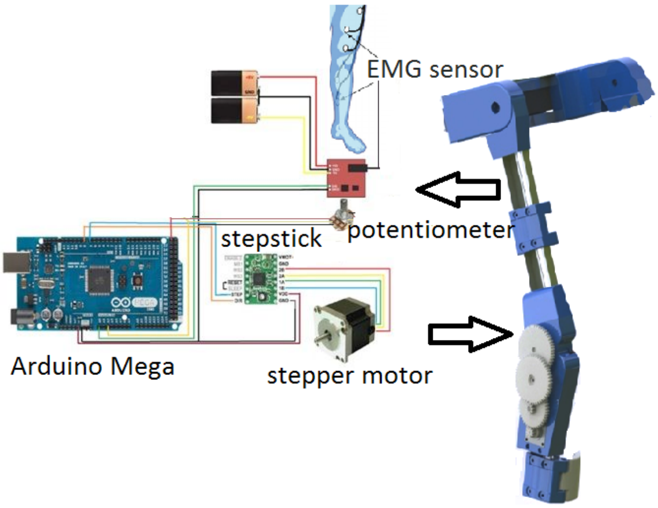

Figure 4 Scheme of the device

EMG sensors should be placed on the skin surface. The surface EMG data were recorded bilaterally on the following muscles: five thigh muscles including vastus lateralis (VL), rectus femoris (RF), semitendinosus (SE), biceps femoris (BF) and tensor fasciae latae (TF), and (2) three lower leg muscles including tibialis anterior (TA), soleus (SO) and lateral gastrocnemius (LG). These muscles were selected due to their relevance to gait.
Individual analysis of EMG signal gives us a possibility to estimate strength of the user's muscles during the rehabilitation process. This information will be used to control this exoskeleton. Then, the appropriately algorithm control was written in C.
This project was based on stepper motor. This motor was used in the prototype of the device. In the next version of the prototype, this motor will be changed to brushless BLDC EC 90 flat motor powered by direct current, which is used instead of controlled commutator brushes. This project was based on Arduino Mega 2560. It is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection. Arduino Mega and EMG sensors are powered by batteries 9 [V]. The rest of the components requires a 12V power supply, which was obtained from the battery. Previously mentioned engines used in this device, are a hybrid stepper motors – series 57BYGH. These stepper motors are in medium sizes. The diameter of the root was increased to enhance torque in this mechanism. Moreover, a Panasonic LC-R123R4PG battery was used in the first prototype. The LC-R123R4PG by Panasonic characterises by a long life, valve regulated rechargeable lead acid battery with FASTON 187 terminal. Nominal voltage is 12V. Nominal battery capacity is 3.4Ah. "TransforMe" with this battery is able to work 2 hours [19].

4. PROTOTYPE

Selected elements of the "TransforMe" were made by the method of rapid prototyping on 3D printer of plastic technical PLA material, in more details they were: the construction of knee joint, fastening of the exoskeleton to user's limbs and parts of the frame structure [20]. This technology allows to quickly create an actual model that we are able to see and test in real life. There is a possibility to assess the quality and dimensions of the designed device. The frame was made of a 2 mm aluminium construction. A specialized belt attached to a pelvis was used to fasten the exoskeleton to user's body. The last parts of this process were the assembly and first tests (Fig. 5).

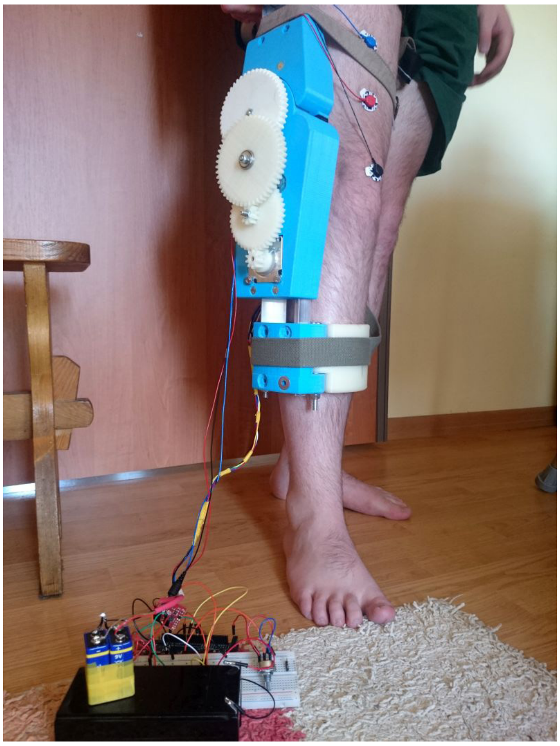

Figure 5 The first tests of the exoskeleton

During these tests, people used this device for rising and sitting on a chair, also walking, including some stairs. First tests consist of the measurement of reaction of muscles. The surface EMG data were recorded bilaterally on the following muscles: five thigh muscles including vastus lateralis (VL), rectus femoris (RF), semitendinosus (SE), biceps femoris (BF) and tensor fasciae latae (TF), and (2) three lower leg muscles including tibialis anterior (TA), soleus (SO) and lateral gastrocnemius (LG). User uses this device for right leg. It is possibility to see a different values of EMG signals for left and right leg. Left leg is in good condition so theses values are higher. In case of right leg we can see a lower values. "TransforMe" helps to user to move. The surface EMG data were recorded bilaterally on the following difference of the maximum values for muscles: vastus lateralis (160 mV) (Fig. 6), rectus femoris (90 mV) (Fig. 7), semitendinosus (110 mV) (Fig. 8), biceps femoris (150 mV) (Fig. 9), tensor fasciae latae (110 mV) (Fig. 10), tibialis anterior (190 mV) (Fig. 11) and soleus (1 mV) (Fig. 12).

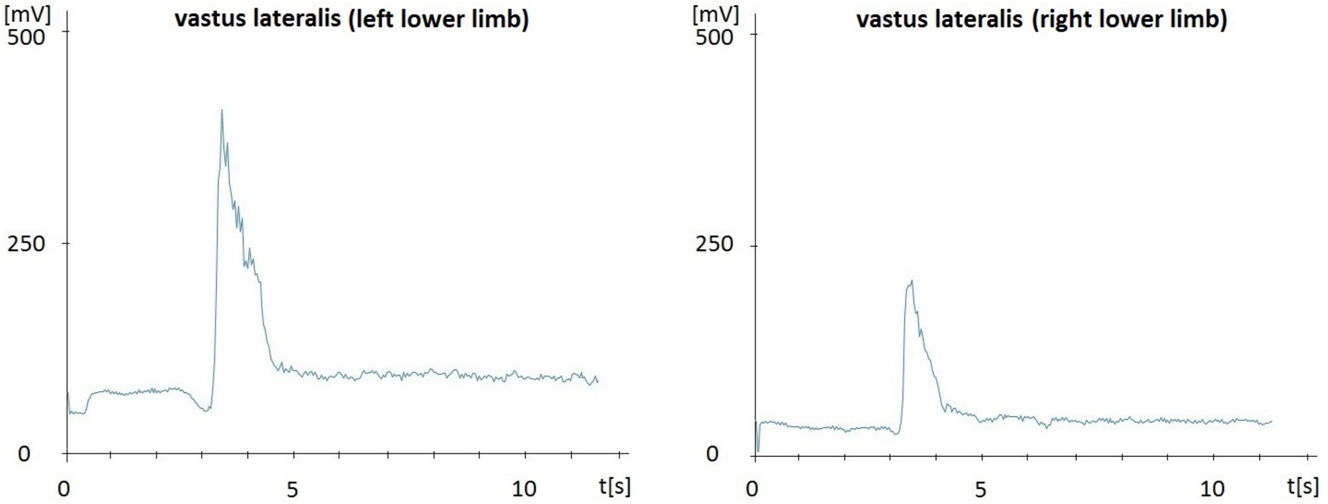

Figure 6 The surface EMG data (vastus lateralis)

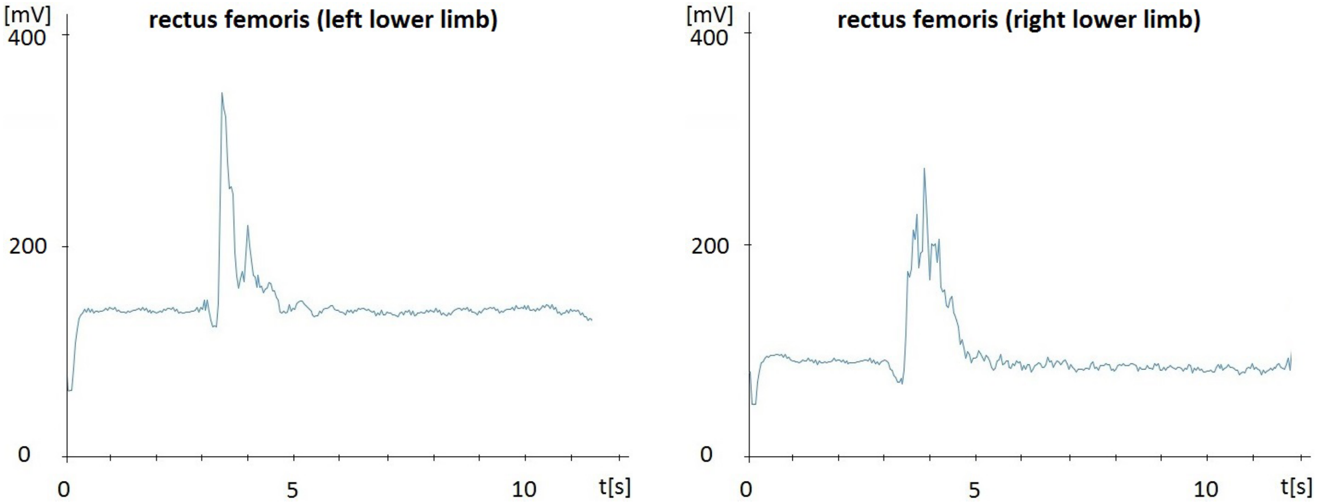

Figure 7 The surface EMG data (rectus femoris)

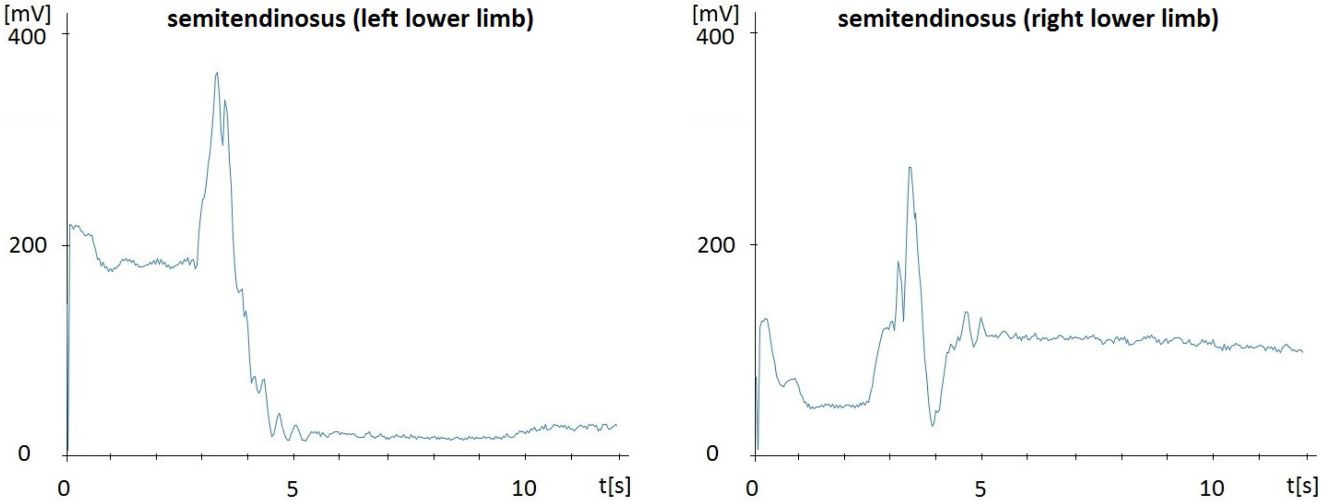

Figure 8 The surface EMG data (semitendinosus)

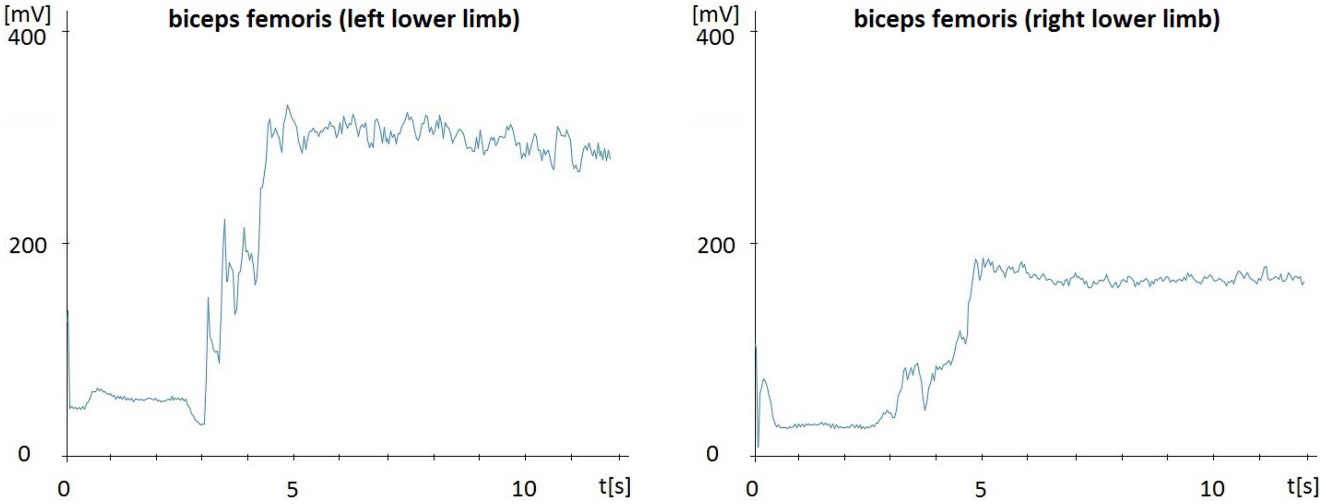

Figure 9 The surface EMG data (biceps femoris)

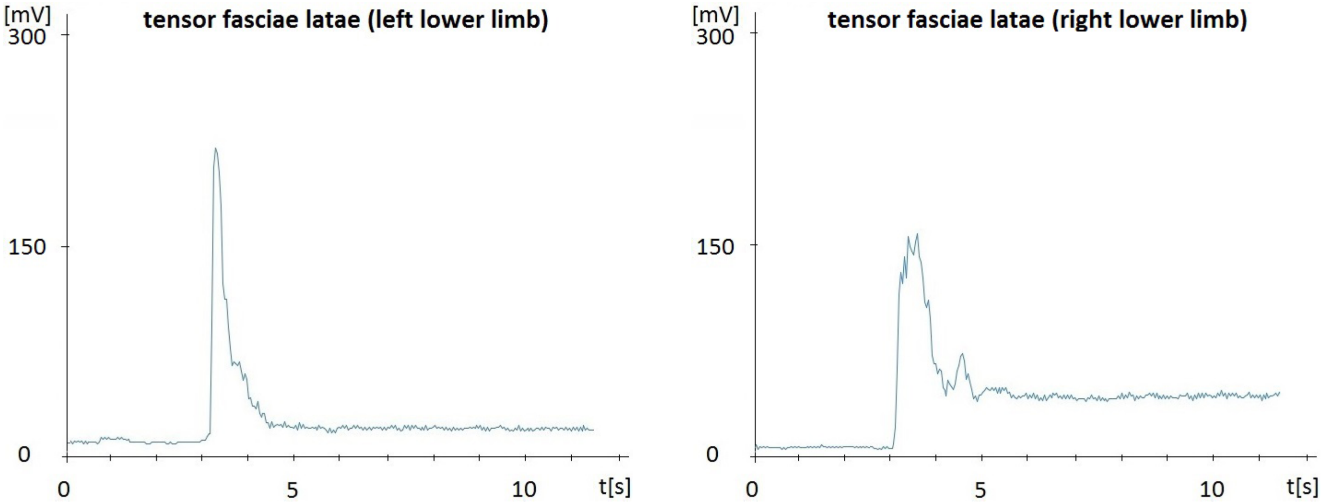

Figure 10 The surface EMG data (tensor fasciae latae)

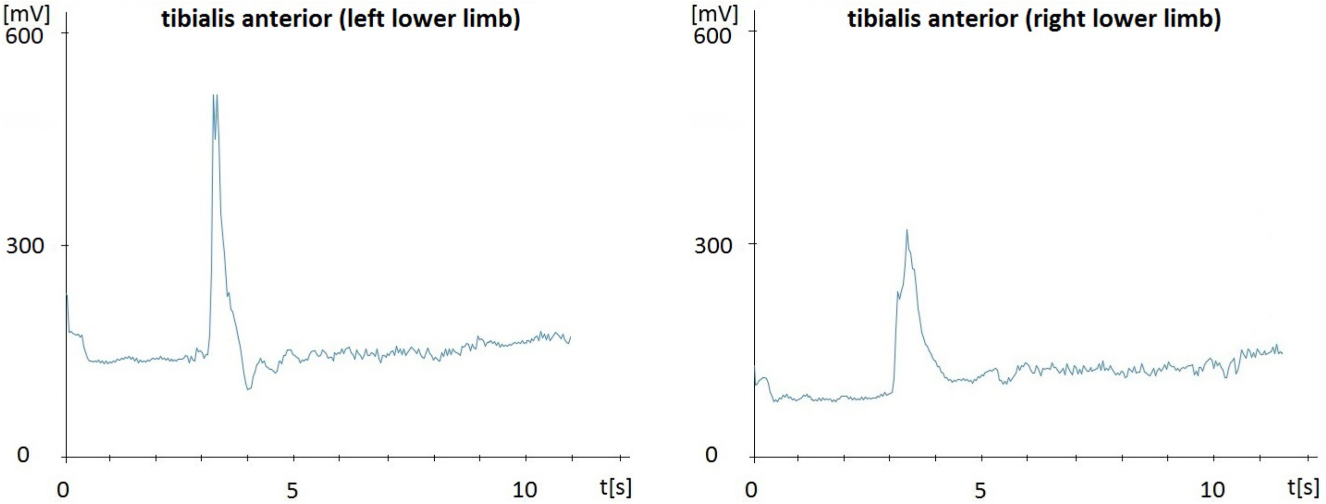

Figure 11 The surface EMG data (tibialis anterior)

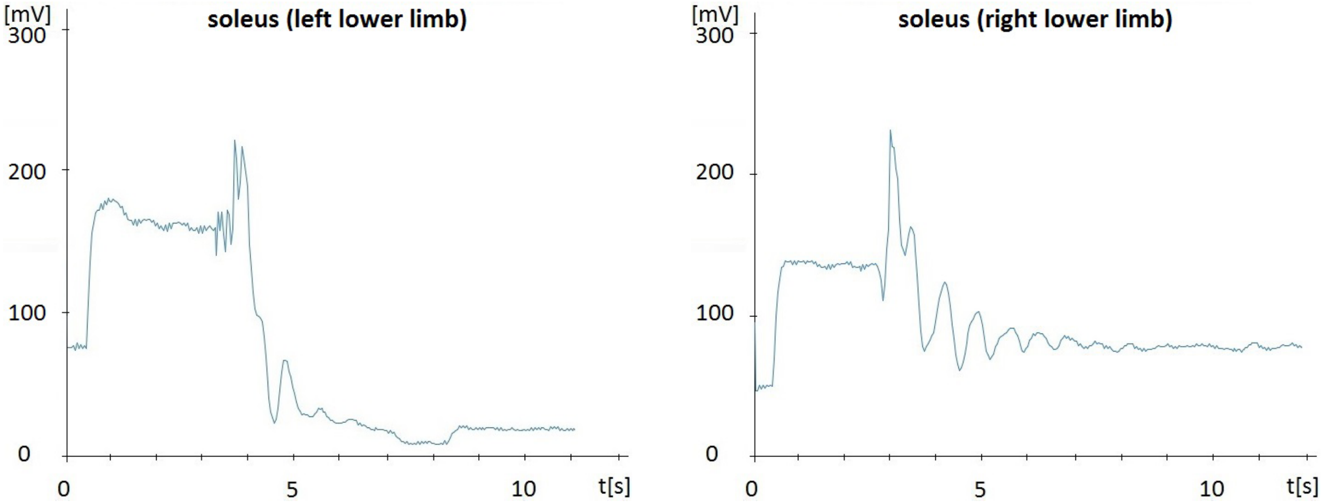

Figure 12 The surface EMG data (soleus)

5. CONCLUSION

The developed exoskeleton “TransforMe” is a mobile solution to support the process of rehabilitation gait (the basic functions of walking, such as sitting down, getting up, going up and down the stairs). The mechanical structure of the device consists of four aluminum rods and a lot of elements, which were made by the method of rapid prototyping on 3D printer. This construction is characterized by lightness and strength. Element supporting the process of rehabilitation is use of electromyography (EMG signals) in order to stimulate the process of reconstruction by the use of biofeedback. The most important objectives of this project include: lightweight construction, battery power supply, adjustable length of the device, EMG sensors to control the device, mobility and the low cost of the prototype. “TransforMe” is an innovative and future-proof solution. Its modular design provides the ability to individually adjust to the expectations of future users.

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