Applied Mechanics and Materials Vol. 464 (2014) pp 129-134
Online available since 2013/Nov/21 at www.scientific.net

doi:10.4028/www.scientific.net/AMM.464.129

Interactive Foot Orthosis (IFO) for People with Drop Foot

Ali Faraji[a], Mohsen Rasouli Valajoozi[b]

Faculty of Industrial Design, University of Tehran, Tehran, I.R. Iran.

[a]faraji@ut.ac.ir, [b]mohsen_rasouli65@yahoo.com

Keywords: Drop Foot; Interactive Foot Orthosis (IFO); Industrial Design; Interaction Design; Biomedical Device.

Abstract. Different reasons in anatomical and physiological systems' defect may cause disorders in proper gaiting process. Drop foot is one of these. These factors effect on one particular muscle called tibialis anterior, locating on tibia. This problem occurs after the treatments of the different leg related disease. This research is designed a novel product to help patients having a normal and standard gait as well as to improve the muscle weakness and movement. It also provides the important expected factors such as functionality, ergonomics, consistency, pleasure, aesthetic, and finally user satisfaction. By making use of interaction design strategy, three functional mechanisms are designed to improve the disease. In order to measure the rate of applied criteria, and potential of new design, the designed products were evaluated by target group. Final conclusion is stated the product is positively developed.

Introduction

If we study some behaviors of the patients in rehabilitation science, many disorders in this field are kinds of abnormalities. In most cases, the abnormal behavior and action appears after the treatment. The “drop foot” is among these in which the treated patient cannot perfectly do the natural motion of walking the way a healthy person can. In this way, the individual cannot move the toes upwards enough, so the leg drags and because of this the person moves the knee more than usual to avoid its dragging on the ground [1]. When a person is gaiting, nerves, muscles and bones make this movement possible by their interactions. Drop foot disorder is the state of feet’s inability to move the toes and dorsiflexion. It occurs when the muscles are restored. Caused by various reasons, it leads to different modes of walking that each of them has a specific name such as: turning up around, beating the toes forward or duck like walking and etc [1]. Generally, the recovery period gets too long after the treatment and the patient should take some exercises with the physician consultation. Frequent physiotherapy sessions will help them get improved in the long run. In fact, the need to a product for the patient to fasten the healing process in a short period without the physician’s precise supervision yet whit their tips, seems to be of utmost importance. This disorder is seen more significantly among the professional athletes. Hence, passing the recovery period is very important to them because it’s the matter of time. Therefore, having such a product could be of a great benefit [2]. Another aspect in recognizing the importance of the topic is to identify the possible users. In general, patients with the foot, knee and shin disorders suffering from drop foot after recovery period are the end users of the product. Among these are: professional and non-professional athletes, patients with broken legs and torn muscles in road accidents, patients with neurological disorders such as polio, brain disorders, nerve injuries in leg, risk of cerebrovascular accident [3], people who are suffering from sclerosis, Stroke that caused by an accident, In this case the muscle nerve Is interrupted and it muscle does not get nervous signal wave, and diseases neuromuscular junction. Also, some of other condition led to the drop foot, such as, muscle performance of patients with hemiplegia, paraplegia in the lower limbs, that has affected on quality of tibialis anterior muscle, so could not be dorsiflexion movement. According to power of gastrocnemius muscle and action of gravity in the swing phase, foot fallen to downward and paw hit the ground, before the hill down action [4].

Important treatment options. In many cases, the patient will be monitored and treated during several sessions by a physiotherapist. The physiotherapist chooses various treatment methods according to the patient’s condition. Some of the treatment solutions are: A) using the variety of

supporters that are proportional to the weight, B) taking exercise therapy to strengthen muscles and joints to take the normal steps, C) using electrical stimulation [5], D) transference and replacement of tendons. In sum, surgery, physical therapy at clinics, using different braces, nerve stimulation and treatment with AFO are several methods for treatment and recovery [6].

Target group and design criteria. Target groups, have been identified thorough observations and researches. Groups have been prioritized, according to the severity of their case and the way they interact with the product, by using the Analytic Hierarchy Process method (AHP) [7]. The priorities are included in three groups of, user (patient) (62%), suppliers/ makers (24%) and physiotherapist (14%). Patients include the people who are suffering from drop foot for many reasons. They are the users of the product and they have the most interaction with it. Suppliers or makers are the professional people that the patients refer to them, they provide a model of foot orthotics, fix it on their shill. Physiotherapists are professional people to whom the patients refer to and they decide how to begin the healing process. They have the less intense relationship with the product. This study is aimed to identify and understand the target group's opinion about the product to formulate design criteria by using three methods of field research questionnaires, interviews and observations. In this regard, 33 opinions of target group members (users, physiotherapists and suppliers) were studied. Information was received from various centers, such as hospitals, clinics, private practices and public hospitals, sports teams and sports federations in different parts of Tehran, (2011-2012) . After combining and refining the design criteria (for designing a drop foot device treatment to help treat foot disability) is obtained as following:

Functional Criteria:

- Capability of easy assembly for suppliers;
- Ability to adapt for each user;
- Creating gait performance in different conditions (walking on the flat and sloping surfaces or walking on the stairs) ;
- Easy access to the suppliers for fixing it;
- Ease of teaching and learning to use of product (Graphic signs and educational brochure)
- Adaptable to the opposite foot during movement;
- Suitable for using in various modes of movement and capable to keep the foot in the standard position.

Ergonomic criteria:

- Appropriate size to adapt foot size in different ages;
- The use of suitable material in the outer and inner part of the product to provide a comfortable position for the foot;
- Comfortable wearing process;
- Considering the light weight of the product for an easy use;
- Modular design, comfortable assembling and a proper ability with the product components;
- Adjustable size for the comfort and stability while contacting with the foot;
- Highly safe design and proper form of the product prevents any further damages to the foot.

Aesthetic criteria:

- Use of colors to make the product appealing;
- Ability to select different colors for different tastes of different ages and it has to use for men and women;
- Use of soft and smooth form with rounded edge;
- Use of suitable form for orthotics products as a brand identity element;
- Use of appropriate texture materials, to create visual attraction;
- Size adjustability;
- Coordination between the various parts and components of the product;
- Use of graphic elements (text and image) for visual appealing.

Some parts of the design criteria, are obtained according to the aesthetic criticism [8].

Interactive Foot Orthosis (IFO): Based on design criteria, and different available operating mechanisms for creation of dorsiflexion motion assistance device, three different classes of designs presented, with an emphasis on proper functionality of a healthy gate. Class No. 1 uses an operating mechanism based on a cache, which is one of the usual ways of dorsiflexion movement creation. By different settings of the cache elasticity, various steps of improvement process can be covered. Low cost production and affordability for users are the main characteristics of this mechanism, (Fig. 1). Class No. 2 applies a bumper mechanism in order to create a jump to the foot in the swing phase of gate. The difference in number, order, position and arrangement of the bumpers help to provide decreasing levels of assistance in four different phase of drop foot treatment toward the complete improvement of abnormality (Fig. 2).

Fig. 1 Lifting mechanism

Fig. 2 Bumper mechanism

Class No. 3 utilizes servo motor mechanism in a way that the servo motor which is located at hill notch area, receives the information from an encoder that is attached to the knee. The encoder is used as a protractor (the angle of knee reaches its maximum while the foot is on the step-down or during gait process). During walking process, the angle of knee depends on the angle of the knee with a large correlation, and protractor with the knee angle acts as an encoder. By using a timing belt, servo motor transmits the motion to the screw on the ankle, then a lever that is attached to the orthopedic insoles, directs toe upward (Fig. 3, 4).

Various steps toward the improvement of abnormality can be applied with this operation mechanism. This class (No. 3) is more expensive than two prior mentioned classes (No. 1 and 2) and is aimed for the high level of recovery importance cases. Due to the limited number of pages, following discussions focuses on the servo motor operating mechanism and its details, which has higher level of innovation and performance.

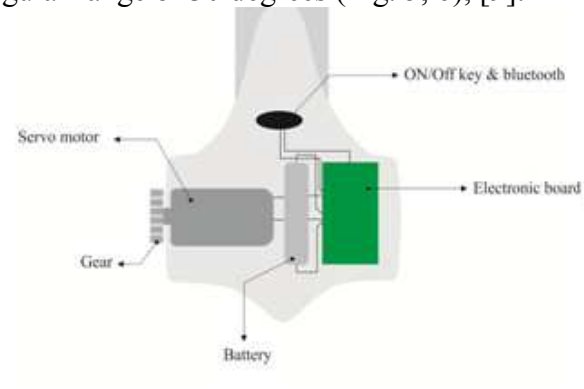
Fig. 3 Servo motor mechanism

Fig. 4 Product side view

Servo motor operating mechanism has two supports, located at two sides of the leg, which holds the ankle in its proper position, preventing its deviation during walking process. In fact these two supporters creates the connection between the lower part (insole) and ankle. As noted, required

information in order to achieve the desired angle is received by another variable during gait that is called knee angle (by an encoder). The knee angle can be used as an important factor of changes for knee in walking process. Adjustment of its ranges differs for each person.

Data transfer is carried out by Bluetooth on the knee to the ankle. The operating mechanism uses 6 watts of power, and it can move the maximum 450 g of foot in the minimum time of 1.3 s with the angular range of 30 degrees (Fig. 5, 6), [9].



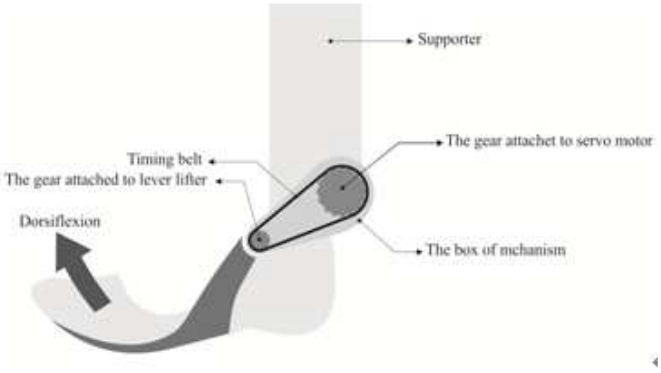


Fig. 5 Servo motor mechanism(behind view) Fig. 6 Servo motor mechanism

The external body inspired by the organic form of the human body, using rounded corners by consideration of target groups tastes, and based on ergonomics criteria. Usage of the flexible materials in the product can improve the foot and product interaction, in contrast with the current devices. It should be mentioned that according to the physician's diagnosis, the insole parts –or any other part- of the product can be molded based on the specific user's foot in order to be more compatible. Location and position of the operating mechanism's parts, proper function can be achieved.form of the product that is consistent with the general form (Fig. 4).

Curved lines, graphics and signs can help create a more attractive product form; in addition they can help the patients, physiotherapists and suppliers to use them as guides. Other features of these designs can be mentioned, such as: the ease of comprehension of the product elements, because of its simplicity, ability to adapt to the different levels of intensity and muscle damages on the tibialis anterior, convenience of using the product and its efficiency during the swing phase, flexible material with suitable dimensions, modifies walking and finds the correct gait with high quality for each patient, walking on the positive and negative slopes (such as going up and down stairs or slopes), and the result of the mentioned factors is an optimal interaction between the user and the product [10].the main components of this product are: supporters on both sides with the carbon fiber composite, surface of servo motor protective with ABS, toe lifter made of carbon fiber composite, straps are made of soft cached plastic, interior cover is made of PU to prevent sweating, insoles and inner lining are made of PU sponge, and the adjusting screws are made of ABS [11]. The main parts and the inner components are shown as exploded view (Fig.7).

Fig. 7 Exploded view of servo motor mechanism

Algorithms of using the product are described as in following:

- Selecting the suitable dimensions;
- Choosing different colors in different parts of the product according to the user's preference;
- Assembly components;
- Wearing the insoles part that is separated with supporter and product mechanism;
- Convenience control that product maker has considered;
- Closing the belt holder and adjusting the size provides the user's convenience;
- Adjusting the stage for improvement condition according to the set screw mounted on product;
- The ability to use with or without (regular or special medical) shoes. This case is suggested by physiotherapist;

After deciding to use the product, the patient is referred to the physiotherapist, and then medical advice or other solutions are given to improve by orthotics. This interaction will continue until the patient is able to walk with a normal gait.

Conclusion

For the treatment of drop foot, an interactive product was presented with dorsiflexion operation in swing phase. During the design process, initially biomechanics of foot movement has been studied, along with drop foot abnormalities and identification of its causes, and ways of treatment. Then field researches based on interviewing and observing target group, and performing questionnaires set out to determine the design criteria. According to the design criteria, drop foot abnormalities' orthotics designed in three different operating mechanisms; which in this paper the servo motor mechanism was presented. Characteristics such as the ability to function on different slopes, specific considerations of aesthetics criteria resulting in visual attraction, consideration of ergonomics principles, and pleasant usage which together results in treatment process effectiveness, can be mentioned. Finally the design evaluated by target group; the results indicated that the groups were satisfied with the device. Which can be considered as an important step toward more effective drop foot abnormality treatment.

Acknowledgment

The authors gratefully acknowledge the support of the University of Tehran of I.R. of Iran during this work.

Corresponding Author

Ali Faraji, Faraji@ut.ac.ir, Tel.: +98-21-6695-5629; Fax: +98-21-6111-2457.

References

[1] Pritchett, J.W., *Foot drop,* United State, American College of Surgeons (2009).

[2] Yan, Z., *Skeletal muscle adaption and cell cycle regulation*, Exercise & Sport Sciences Reviews New York, world press (1999).

[3] Voigt, M. and Sinkjaer, T., *Kinematic and kinetic analysis of the walking pattern in hemiplegic*, Clinical Biomechanics (2000).

[4] Donnelly, G.M., Lyons, T., Byrne, C.A., O'Keeffe, D.T., *Effect of walking speed changes on tibialis anterior EMG during healthy gait for FES envelope design in drop foot correction*, Journal of Electromyography and Kinesiology (2007).

[5] Kamen, G. and Gabriel, D., *Essentials of Electromyography,* Human Kinetics, United State (2010).

[6] Chusid, M.J. and Jacobs, W.M., P*seudomonas Arthritis Following Puncture Wounds of the Foot*, United State, Journal of Pediatrics (1971).

[7] Saaty, T.L., *The Analytic Hierarchy Process, Planning, Piority Setting, Resource Allocation*, united state, new york, Mcgraw-Hill (1980).

[8] Bardzell, J., *Interaction criticism, how to do it*. New York, World Press (2009).

[9] http://www.mclennan.co.uk/dcservo.html (as of mar 2013)

[10] Rogers, Y., Sharp, H. and Preece, j., *Interaction Design: Beyond Human - Computer Interaction Computer Interaction, 3rd Edition*, John Wiley & Sons, England (2011).

[11] http://www.oandp.com/articles/2008-02_13.asp (as of Apr 2012).

Intelligent Materials and Mechatronics
10.4028/www.scientific.net/AMM.464

Interactive Foot Orthosis (IFO) for People with Drop Foot
10.4028/www.scientific.net/AMM.464.129