Impact of Fixed and Non-Fixed Foot Orthoses on Fatigue of Lower Limb Muscles

Zhi TANG[1], Li LIU[2], Shengze WANG[1], Zhihui LIU[1], Yuxiang QIU[1], Xi HOU[1] and Qian WANG[3, a]*

[1]College of Mechanical Engineering, Donghua University, Shanghai 201620, P.R.China.
[2]Engineering Technical Training Center of Shanghai University, Shanghai 200444, P.R.China.
[3]Shanghai General Hospital, Shanghai 201620, P.R.China.
[a]14141189@qq.com

Abstract — **Our research focuses on the two types of foot orthoses (fixed and non-fixed types) used by cerebral stroke patients for foot drop treatment. The aim is to investigate their impact on the fatigue of the main muscles of the lower limbs. Using electromyography signals, we measured the activities of different muscles, including biceps femoris, rectus femoris, tibialis anterior, and gastrocnemius. Then the impact of the two types of orthoses was compared. Results show for the non-fixed ankle foot orthoses (AFO), the amplitude indicators of the calf muscle are larger than the fixed one. The reduced frequency difference for the non-fixed AFO was greater than for the fixed AFO. Also, the laboratory parameters of the thigh muscle were similar between the stationary and non-stationary one. We conclude: when wearing non-fixed orthoses, the shank muscles receive recovery and the cooperation between the thigh and shank muscles improves. Also, it is noticeable that long-time walking rehabilitation training in orthoses can result in fatigue. When wearing fixed orthoses, the activity of the shank muscle is not obvious, and the participation of thigh muscles does not differ a lot from that in the non-fixed type. The activity level is significantly different compared with the situation in which there is no orthoses limiting the ankle movements. The cooperation of thigh and shank muscles is relatively poor during walking, and the thigh muscles tend to develop fatigue over time.**

Keywords - foot orthoses, surface electromyography, muscle fatigue, time domain analysis, frequency-domain analysis

I. INTRODUCTION

Foot orthoses are mainly used for recovering from a range of movement disorders that can physically change the functioning or structures of nerves, muscles, and bones by applying force [1]. They are generally applied to patients who suffer from central nervous injuries, such as cerebral stroke, traumatic brain injury, or cerebral palsy, to correct varus foot, valgus foot, and foot drop [2]. The effects of foot orthoses include sustaining paralyzed muscles, steadying and protecting joints from body weight, and sharing the body weight [3,4].

According to related research from a database [5-9], studies on foot orthotics largely focus on its application in various disorders and its impacts on these disorders. Using biomechanics and gait analysis, the factors being adapted include step length, speed step frequency, swing angle of lower limbs, joint matrix, and balance ability.

Divided by the basic functions, the earliest and most commonly used type was the plastic fixed foot orthoses; in its development, the material and way to fix the ankles' position have been improved. This type of orthoses fixes the ankle, making the bottom of the foot perpendicular to the shank and restricting the ankle's dorsiflexion and plantarflexion. Another type of orthoses that has been effective received much attention, allows the ankle to move to some degree and enables dorsiflexion. In the following research, the former type will be named fixed (foot) orthoses, and the latter will be named non-fixed (foot) orthoses. The two types are applied to similar conditions, suitable for correcting varus foot, valgus foot, and foot drop. Studies have indicated that the two types of orthoses are to be applied in different phases of the same condition. However, in clinical practice, these applications are not clearly distinguished and become rather complicated, resulting from variations of the condition, functions, and prices [10-13].

The most common treatment is the three-point system. By applying force, the functions of the paralyzed muscle can improve, the weaker muscle gets exercise, and the joints can stay in the functioning position to support the normal movement. Foot orthoses of this kind have significant effects on correcting limb deformity and postural abnormalities, maintaining the joints and walking posture, but negative effects on patients' lower limbs will emerge when applying the foot orthoses. Improper use of the product can easily cause side effects, such as muscular atrophy or amyosthenia. Meanwhile, the joint movements are directly connected to the muscles, allowing dorsi flexion and plantar flexion, which accompany the stretching and folding of the knee that are controlled mainly by the biceps femoris muscle and rectus femoris muscle [14]. As a result, these four muscles have significant influence on evaluating the limb recovery state. In recent years, the activity of human muscles has been studied. In 2005, Romkes compared the different reactions from underaged patients having cerebral palsy when wearing and not wearing orthotics. It is found that orthotics actually reduced the activity level of tibialis anterior when finish walking motion [15]. In 2007, Willen studied the integral and average values of rib muscles in patients with hemi-paralysis walking with orthotics on [16]. In 2015, through analysis on muscle activity levels, the comparison of the impacts of different orthotics on foot drop syndrome was made by Zollo [17]. These studies provide reference for this subject, as well as its research significance.

Meanwhile, with the development of its processing method , electromyography (EMG) is becoming a necessary and important technique for analyzing foot orthoses. It can be used to record bioelectricity in muscles, so as to estimate the muscle functioning and help to diagnose it [18]. It is common to use EMG to record and study muscle fatigue in sport recovery research. Surface EMG is used to show the one-dimensional time series signals of the neural-muscular system recorded from the skin surface, and its value depends on the activity unit amount, activity unit pattern, and metabolism [19,20]. Muscle fibers are normally controlled by nerves. Various disorders can cause damage to the nerves, making them unable to control muscles. This causes abnormal EMG results. Through analyzing the EMG spectrum, the fatigue could be evaluated, and the proper amount of rehabilitation training could be recommended, thus improving the effect of rehabilitation [21].

Research that especially focuses on the impact of the two types of orthoses on the fatigue of lower limb muscles has so far not yet been seen. Our research aims to investigate the impact of the two types of orthoses on the fatigue of the main muscles on the lower limb on cerebral stroke patients during their recovering from foot drop.

II. SUBJECTS AND METHOD

sEMG was collected from patients with foot drop syndrome:

The experiment was performed in the rehabilitation center in No.1 Shanghai people's hospital in October 2015.

The participants were included if they:

1. Had cerebral stroke for the first time, which caused light foot drop

2. Had more than 1-month's course

3. Were able to participate in the walking training and have no cognitive dysfunction

4. Had shanks not too thin to hold the fixation band when wearing the orthoses.

Twenty patients were chosen for the experiment (10 male, 10 female), with a mean age of 57.2 ± 7.8 years (age range: 43.5 to 69.6 years).

A. Materials

The fixed and non-fixed foot orthoses used were from a common brand available in local stores. The brand of the products is ober, which is made in Shenzhen.

Fixed orthoses almost totally restricted ankle movements. The materials of the products were similar, including nylon, foaming rubber, Velcro tape, and aluminum sticks. It totally fixed the ankle joint (Fig.1).

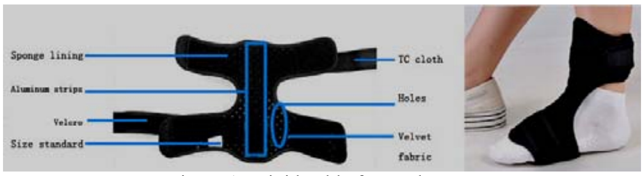

Figure 1. Rigid ankle foot orthoses.

As for the non-fixed type, the product by Win Health (WH-1106) was chosen. It allowed the ankle joint to realize dorsi flexion to a relatively larger degree (Fig.2). The materials of the two products were very similar and skin-friendly, so the variants could be controlled.

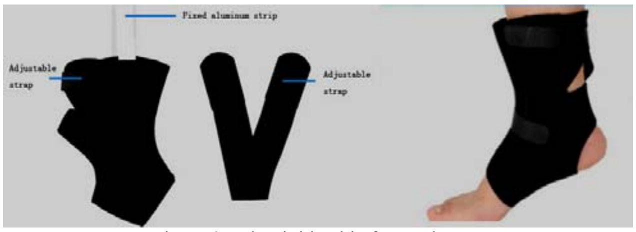

Figure 2. The rigid ankle foot orthoses.

B. Research Methods

The main equipment was the Bluetooth-enabled multi-parameter biofeedback instrument (manufactured in Netherlands)(Fig.3). It has a wide range of use in medical research, including in physiology and psychology. The instrument is CE passed and FDA approved. The EMG is supposed to be very subtle and easily disturbed, so there are enlarging and filtering circuits inside, which enlarge the signals by 1000 times and also exclude part of the noise. The electrodes are produced by 3M, consisting of the conductive paste and (Ag-Agcl) boards, as shown in Picture 2-2. Biotrace+ EMG interface was adapted as the software to the instrument. It enables functions, such as system initialization, data receiving and saving, and EMG wave display, so it is capable of data analysis, data storage, and display.

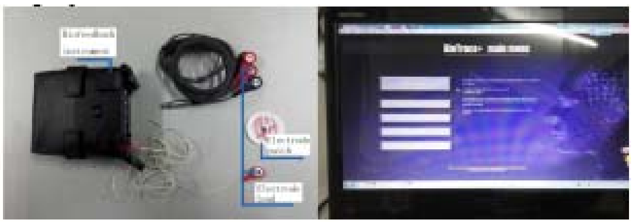

Figure 3. Methods of electricity acquisition system.

The signal collection can begin after all required equipment has been connected to a computer, in which the collecting system program is running. A file is created to save the data collected for later analysis. By clicking the collection button, the system will be initialized and start to collect signals. The interface is shown below.

(1) Applying the electrodes

The EMG signals are collected from four muscles in the lower limb: tibialis anterior, gastrocnemius, rectus femoris, and biceps femoris. When the ankle is free, tibialis anterior and gastrocnemius enable the ankle joint to realize dorsiflexion and plantarflexion. Meanwhile, these movements are accompanied by the stretching and bending of the knee joint, which is mainly controlled by rectus femoris and biceps femoris.

The technique for locating the muscles:

Tibialis anterior: when a healthy, normal person does dorsiflexion, the muscle that bulges out on the front side of the shank

Gastrocnemius: when a healthy person stands fast on tiptoe, the muscle that bulges out on the calf

Rectus femoris: when a healthy person stretches one knee, the muscle that bulges out on the front of the thigh

Biceps femoris: when a healthy person bends one knee, the muscle that bulges out on the back of the thigh.

The electrodes are to be applied on the leg. For each of the four muscles, electrodes should be placed one centimeter both above and below the midpoint of the vertical axle of the venter. The reference electrodes are to be applied on the spine. It is recommended to use ethyl alcohol to clean the skin where the electrodes will later be placed.

(2) Procedure

Before the experiment, every participant was given the two kinds of foot orthoses that they would test. They were then informed of the process of the test. Every time before the test began, participants were required to put on the foot orthoses and walk on a 5-meter-long path for approximately 15 minutes, so that they could adjust themselves to the setting. Another 0.5 hour pause was given while the instrument was being settled. Then the experiment began. The participant was required to walk naturally. The pace, which is controlled during the test, was approximately 50 steps per minute. Fixed orthoses were tested first and then non-fixed ones. Each of the two tests for one participant lasted for 15 minutes, during which the signals were collected. Between the two tests there was a 0.5-hour intermission.

C. Methods of analysis.

EMG amplitude and spectrum analysis. The EMG amplitude and muscle tension were a force-electric correspondence, so time domain indexes reflected the real level of muscle activity. To form a composite of various muscles, muscle contraction force, power output, and the changes of sEMG amplitude must have a good linear relationship. Commonly used indicators are integrated electromyogram (iEMG) and root mean square (RMS).

Frequency domain analysis of the parameters to quantitatively evaluate the frequency spectrum of muscle contraction caused by the frequency median are median frequency (MF) and mean power frequency (MPF).Some scholars has found either for dynamic or static movement, the Fourier spectrum curve will usually be able to move to the left with the generation of fatigue, and MPF and MF decreased accordingly, and time domain indexes of RMS is within a certain range of load on the rise [22,23].

III. EXPERIMENTAL DATA ACCQUISITION AND RESULTS

For the statistical analysis using SPSS software which is form IBM SPSS CHINA for data analysis, differences among groups were compared with the double factor variance analysis. $p < 0.05$ was considered significant. In the experiment, for each muscle corresponding to the different orthoses and acquisition of each signal, the number according to the types of extracted EMG signals and then the extracted EMG signals were transferred into to SPSS for processing.

A. Time domain analysis.

In the time domain, we made a average amplitude analysis. Because the middle subjects had relatively good stability and the subjects of muscle tissue fully mobilized, the subjects selected solid 15 min intermediate time time length (4500-4502 s). This is a gait cycle of the period of time around 2S that is collected to make data analysis.. For 10 times, each time the data was obtained as the mean frequency. Data extraction was divided into the two types of ankle foot orthoses in the 20 subjects, so for 4 subjects, there was a total of 160 categories of muscle group data. Because the 20 samples corresponded to the same type of ankle foot orthoses with a muscle type between the two groups, the data were averaged to eight sets of data. Finally, the average EMG amplitude representing the muscle activity level was derived directly by Biotrace+ software; the data frequency range was 20-500 Hz, and the number of sampling data was 32 per second . The number of original amplitude data in per minute was 32 through mean calculations. There are 64 number in 2 second. Then a gait cycle was divided into 10 points averagely. Because the first two numbers and the last two numbers was give up, we got 60 numbers in a gait cycle finally.

The average amplitudes are shown in Table 1. The gait cycles were divided into percentages of 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%.The nonstationary type and stationary type in Figures 4–7 correspond respectively the non-fixed ankle foot orthoses and the fixed ankle foot orthoses. For comparison of the amplitude change between the two forms of ankle foot orthoses , we select 60 raw data of each group to make waveform figures. Gait cycle is placed on the abscissa and average amplitude is placed on the ordinate in these four figures. The unit of amplitude is microvolt for Figures 4–7. This series of waveform figure was used to judge the muscle activity. Because the of individual differences of the date we got ,we use the average value.Because both of time and ankle foot orthoses types will result in changes of the muscle activity ,we analyzed the influence of these two factors in data processing stage.You can see the details in Table 2

.

TABLE 1. EMG MEAN AMPLITUDE OF 10 PERIODS OF A GAIT CYCLE(MV)

Type of orthosis	Position	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Fixed type	Anterior tibial muscle	43.449	37.308	27.685	43.637	48.915	62.356	50.953	47.675	52.996	47.255
	Gastrocnemius muscle	25.313	21.670	23.856	15.064	14.490	34.239	80.577	57.024	47.475	54.314
	Rectus	14.104	17.228	18.044	12.036	14.147	27.430	24.102	31.366	24.693	17.064
	biceps femoris	18.714	9.074	12.361	26.049	29.976	22.998	14.306	21.545	15.927	20.909
Non fixed	Anterior tibial muscle	23.830	37.637	22.111	23.370	36.240	48.704	25.741	34.061	49.640	32.268
	Gastrocnemius muscle	22.753	24.926	16.295	24.776	47.285	38.796	70.318	100.010	55.416	52.404
	Rectus	16.454	16.073	15.927	10.030	13.007	13.007	29.473	27.369	25.989	23.327
	biceps femoris	27.850	18.171	13.298	8.415	11.365	12.446	17.736	16.968	22.849	24.841

TABLE 2. THE VALUE OF P

	Anterior tibial muscle	Gastrocnemius muscle	Rectus	Two femoral head
time interval（%）	0.014	0.180	0.020	0.876
Type of orthosis	0.001	0.005	0.614	0.604

Results: The activity of the calf muscle, tibialis anterior muscle, and gastrocnemius muscle with the two kinds of corresponding ankle foot orthoses is shown in Figures 4 and 5. For the amplitude of the tibialis anterior muscle, the number of the non-fixed orthoses is bigger than the fixed one in the third and ninth stage of the gait cycle. The result is the opposite in the remaining stages of the same gait cycle.

The average number of data in table 1 show that the non-fixed's data is almost greater than the fixed one. From the table 2, we've learned orthoses type has a significantly influence on amplitude changes of tibialis anterior muscle($P = 0.001 < 0.05$) and time also has obvious influence on amplitude change of tibialis anterior muscle($P = 0.014 < 0.05$). Wearing the different types of ankle foot orthoses made the anterior tibial muscle activity changes; wearing non-fixed ankle foot orthoses increased activity over wearing the fixed one. This explains that, in a gait cycle, amplitude data will have greater volatility; the waveform shows that the gait cycle in the middle of the value will be higher, and ends will be low, which is consistent with the muscle activity for the human gait.

For the amplitude of the gastrocnemius in figure 5, the number of non-fixed type is bigger than the fixed one in the first half stage and the result of the two type is similar in the last half stage.For table1 the data of non fixed is less than

DOI 10.5013/ IJSSST.a.17.29.30 ISSN: 1473-804x online, 1473-8031 print

the fixed value in 10%, 30%, and 70% three node. For the gastrocnemius, orthoses type has a significantly influence on amplitude changes (P = 0.005 < 0.05), and the impact of the change of amplitude of time is not particularly significant (P = 0. 180 < 0.05).

Wearing different types of ankle foot orthoses changes the muscle movement situation in the gastrocnemius. While in the second half of the gait cycle , the non-fixed numbers are smaller than the fixed one. For the fixed type, number of amplitude in half gait cycle approached zero, number of the other half gait cycle increases suddenly and made obvious differences, rather than for non-fixed type numerical integral difference is small. It showed gastrocnemius lifecycle participation is greatly improved.

Thus, due to the non-fixation of the ankle joint restriction, in the complete gait cycle of the anterior tibial muscle and gastrocnemius muscles, these muscles are more involved in the complete gait process.

Figures 6 and 7 show a comparative analysis of thigh muscle rectus femoris and vastus biceps activity. The amplitude value of rectus femoris in Figure 6 showed the basic trend of non-stationary and fixed ankle foot orthoses is the same in the whole gait cycle. Table 1 also shows similar rule of the average values with the one showed in figure 6. Table 2 shows the period in the rectus femoris muscle contraction of numerical changes that have greater influence (p = 0.020<0.05), and the relative influence of the types of orthoses is not obvious (p = 0.614>0.05). Wearing a different type of ankle foot orthoses does not have a significant impact on the thigh muscle movement and different stages of gait cycle made different.activities of the rectus femoris muscle.

Figure 7 shows the biceps femoris muscle activity of the femoral head in the 0% to 30% gait cycle; the non-fixed type is higher than the fixed type. In the 30% to 60% stage of non-fixed type and in the 60% to 100% phase, the data are similar. Table 1 in the data showed a similar pattern. However, from the point of view of the overall stability, non-stationary data changed more smoothly and orderly. Table 2 shows, in time and orthoses type, that two factors of the data changes were not an obvious effect; it was not significant (the former, p = 0.876>0.05; the latter, p = 0.604>0.05). Table 2 also illustrates that wearing different types of ankle foot orthoses does not have a significant impact on the thigh muscle movement effect, and the effect of time factors was also not significant.

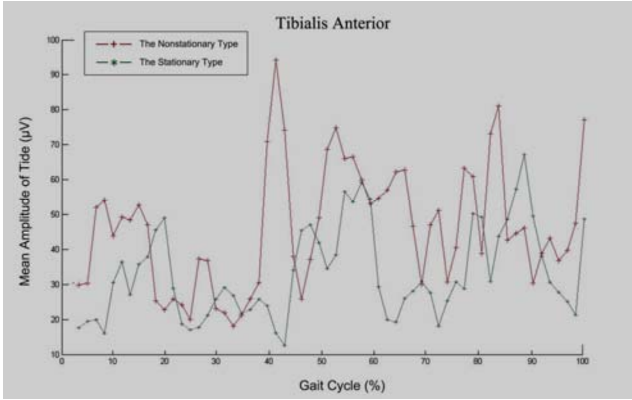

Figure 4. Comparison of anterior tibial muscle.

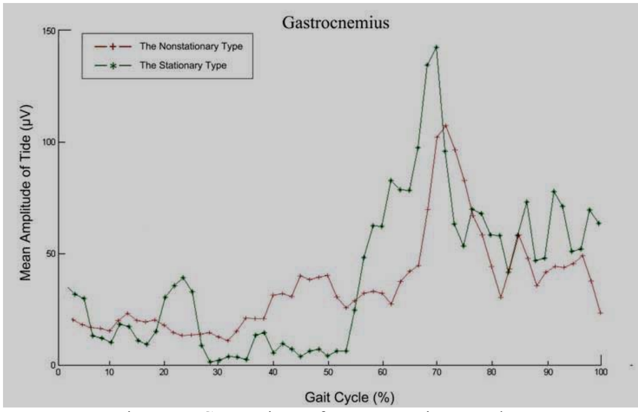

Figure 5. Comparison of gastrocnemius muscle.

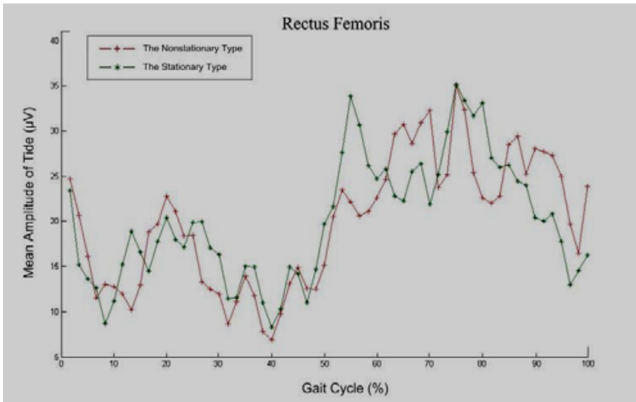

Figure 6. Comparison of the rectus

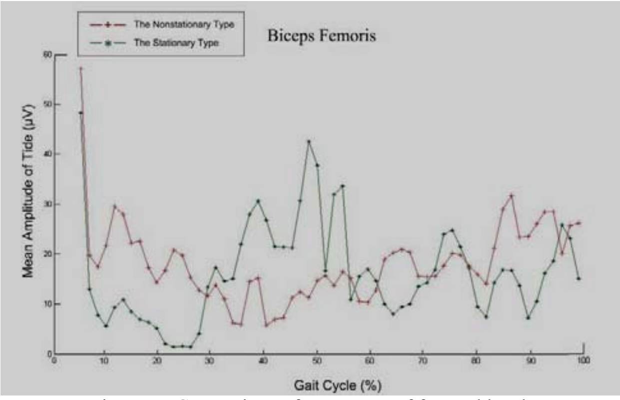

Figure 7. Comparison of two cases of femoral head.

B. *EMG spectrum analysis.*

Frequency spectrum analysis was performed using the average frequency (mean frequency [MNF]) index. When selecting the data, the 15-min walking motion was used, and two of the pre 5-min and post 5-min periods showed a stable pattern of gait cycle. The paper made a comparison of date of average frequency in 750s-752s and 150s-152s . Time was divided into two types of ankle foot orthoses, with 20 samples of four muscle and two time periods, for a total of 320 groups of data. An average value of data was taken for the 20 subjects and two periods of the same kinds of ankle foot orthoses with a muscle type, to get the final 16 data values. The Biotrace+ software used in the experiment can record the frequency changes directly. The collected data were in the frequency range of 10 to 200 Hz, and the data sample was 32 numbers per second. The mean originally had 16 sets of data; each had a number of 32. The finally 32 numbers and average from the 16 data are shown in Table 3. In addition, two 2 s period and ankle foot orthoses types was regarded as two important factors. And then i made two-foctor variance analysis to judge situation of muscle fatigue.

TABLE 3. EMG AVERAGE FREQUENCY OF 2 GAIT CYCLES IN 15MIN WALKING MOTION (HZ)

Type of orthosis	Position	1-5min	10-15min
Fixed type	Anterior tibial muscle	93.763	88.496
	Gastrocnemius muscle	92.325	87.825
	Rectus	85.232	77.240
	Biceps femoris	81.704	73.703
Non fixed	Anterior tibial muscle	89.069	80.811
	Gastrocnemius muscle	86.975	82.200
	Rectus	87.459	80.248
	Biceps femoris	85.125	78.650

Results: Table 3 shows the mean frequency values for four muscle types, tibialis anterior muscle, gastrocnemius, rectus femoris, femoral biceps in two time stages. It made a same rule that numbers of first stage were smaller than the second one . Two periods of time and an average frequency of the fixed stype of the tibialis anterior muscle, gastrocnemius, rectus femoris muscle, and biceps were decreased by 5.61%, 4.87%, 9.37%, and 9.79%, respectively, and the average frequency of the non-fixed type in the wearing state a decreased by 6.04%, 5.49%, 8.45%, and 7.61%, respectively.

TABLE 4. P VALUE

	Tibialis anterior muscle	Gastrocnemius	Rectus femoris	Biceps femoris
Orthotics Types	0.018	0.031	0.499	0.171
Times	0.045	0.047	0.038	0.035

Table 4 shows the time foctor had a great effect on the average frequency of time for tibialis anterior and gastrocnemius (P = $P=0.045<0.05$, $P=0.047<0.05$). Frequency of tibial anterior muscle and gastrocnemius muscle reduced over time and musclehad the trend of fatigue. orthoses type has great influence on the average frequency of tibial anterior muscle and gastrocnemius muscle (P = $P=0.018<0.05$, $P=0.031<0.05$). It showed different orthoses made the same muscle type produces different frequency value, and its influence on muscle fatigue degree is different. Comparing the number value of orthoses with diffirent type in table 3, we found the fixed is the bigger one in tibialis anterior muscle and gastrocnemius (6.04%>5.61%, 5.49%>4.87%).

At the same time, the time factors will also have a great impact on the average frequency of the rectus femoris and biceps femoris($P=0.038<0.05$, $P=0.035<0.05$), such that the time changes of the frequency value of the rectus femoris and vastus biceps were indeed declined and trending to muscle fatigue. There was no significant difference in effect of the orthoses type factors of tibialis anterior muscle and gastrocnemius muscle in the mean frequency change ($P=0.499>0.05$, $P=0.171>0.05$). These results illustrate that different orthoses making the two muscle types produce different frequency values does not play a strong role. The degree of differences in muscle fatigue mainly varies with time.

From the amplitude data and comprehensive analysis of the frequency data, the amplitude data display that the activity of tibial anterior muscle and gastrocnemius muscle increases by wearing a non-fixed ankle foot orthoses compared with the steady one. The corresponding frequency data show that the MF for the tibialis anterior muscle and gastrocnemius muscle decreased greatly. This analysis suggests that calf muscles get exercise recovery when the subject wears a non-fixed ankle foot orthoses; this may allow a certain degree of ankle range of motion and make a good condition for collaborative movement of the calf and thigh muscle. At the same time, attention must be paid to the length of time wearing the orthoses because wearing it for long periods of walking training trends to cause fatigue.

The level of calf muscle activity was low while wearing a fixed ankle foot orthoses. Thigh muscle movement had little difference between the non-fixed product and the fixed product, but compared with the condition without orthoses, there is a large difference for thigh muscle movement. When the walking leg and thigh muscle movement coordination was poor, the calf muscle for a long time walking was prone to muscle weakness and atrophy; with an increase in the movement time, the thigh muscles will more easily enter a state of fatigue.

IV. DISCUSSION AND CONCLUSION

In our experiment of two different forms of inquiry using stroke patients with foot drop symptoms during rehabilitation (fixed and non-fixed) of the ankle foot orthoses worn during the treatment of involved lower limb muscles, we mainly observed fatigue. Our initial results demonstrated the influence of non-fixed ankle foot orthoses on the improvement of thigh and leg muscle coordination and movement. Because of reducing restrictions of dorsiflexion and plantar flexion movement on the ankle joint, there was an increase in the activity of the calf muscles, tibialis anterior and gastrocnemius, compared with the fixed ankle foot orthoses. At the same time, the rehabilitation in subjects wearing the non-fixed ankle foot orthoses, the thigh muscle was fatigued, and muscle activity in the non-fixed complete walking action was slower. The sudden force and recovery of the situation was relatively small and reduced the consumption of energy needed for walking.

The results of research is similar to Zhang Jinhua’s. They all showed non-fixed ankle foot orthoses can help to correct foot drop, while providing walking foot dorsiflexion function and improve walking and balance. Just Zhang Jinhua [24]assessed teh evaluation by the gastrocnemius muscle spasticity score (modified Ashworth value MAS), range of motion of the ankle (ROM), Berg balance scale (BBS) and gross motor function scale (GMFM) of the D area and F area percentage and other parameters.

Zollo use electrophysiological index to compare influence fo the musle with different types of orthoses, and it showed fixed ankle foot orthoses will usually increase muscle contraction and common walking process. When wearing the orthoses, common sports level of calf and thigh muscle is higher, and it is more close to the normal mode and similar with the results of this paper. Other studies like Yi Nan’s, Qu Qingming’s, and Bing Shui Wang’s have shown that different design types of ankle foot orthoses can be controlled in the sagittal plane and coronal plane of ankle foot movement, relieve spasm, and improve walking speed and stride length. To make equal comparisons of the influencing factors of both sides in terms of the velocity of movement, in our experiments the pace was controlled as invariants. The clinical significance of this study lies in the formulation of relevant guidelines help with ankle foot orthoses adaptation.

Future research should evaluate human lower extremities more comprehensively and with accurate consideration of overall gait training with ankle foot orthoses and recovery. Adding a control of a healthy person's feet (not wearing any type of ankle foot orthoses) and healthy people wearing ankle foot orthoses in case of data types would also provide more abundant types of samples for the next stage of the study and be compared to data types in detail. For the ankle foot orthoses product, we can also study more various types of products, can consider the division of the range of movement Angle of the ankle. In short, the corresponding research is more in-depth with a wider range of possibilities. The current research will provide the methods and results as a reference for future work.

However, there are some deficiencies in the experiment. On one hand, the sample number is not large enough, due to experimental resource limits. EMG reveals individual differences; each patient's muscle prevalence and their muscle activity is similar but not identical, when evaluating the overall level of EMG signal differences. Certain differences also exist in subjects’ walking gait speed. Also for statistical data was selected in a broad range ,not in a particular time. The experimental parameters were not comprehensive enough, such as the time domain analysis in addition to the RMS and the level of electrical activity (EA) and iEMG values.

In addition, there were some other uncontrollable factors, such as the stability of the psychological change or experimental equipment. In the experimental process, there were three subjects in the testing process during which the EMG signal was interrupted or there was no signal feedback; after a period of time, the equipment returned to a normal collection signal state, so the stability of the equipment may have somewhat influenced the results.

The experimental results can give advice in the actual clinical disease of fixed and non fixed ankle foot orthoses and have certain directive significance to the product design application. We also found there are some researchers who design new product for patients with ankle foot orthoses for a long time and it aimed to make patients control the the activities of the ankle as soon as possible. Fixation showed that ankle orthoses is changing; the research direction will be more in-depth and detailed [25,26]. However, different ankle foot orthoses on limbs will produce different effects; therefore, it also requires clinicians and researchers to continue the efforts to design the most appropriate ankle foot orthoses and to assemble patients for testing.

ACKNOWLEDGMENTS

This project was supported by Fundamental Research Funds for the Central Universities; Research Innovation Project of Shanghai Municipal Education Commission; Science and Technology Guidance Project of Chinese Textile Industry Association.

REFERENCES

[1] Lamb PF, Mundermann A, Bartlett RM, et al. Visualizing changes in lower body coordination with different types of foot orthoses using self-organizing maps (SOM). 2011;34(4):485-489.

[2] Woodburn J, Barker S, Helliwell PS.A randomized control edtrial of foot orthoses in rheumatoid arthritis. JRheurnatol.2002;29(7):1377-1383.

[3] Wall JC ,Turnbull GI. Gait asymmetries in residual hemiplegia. Arch Phys Med Rehabil.1986;67(8):550-553.

[4] Cruz TH, Dhaher YY. Impact of ankle-foot-orthosis on frontal plane behaviors post-stroke. Gait Posture.2009; 30(3):312-316.

[5] Van Swigchem, Root, Roerdink, Melvyn, Weerdesteyn, Vivian, Geurts, Alexander C, Daffertshofer, Andreas. The Capacity to Restore Steady Gait After a Step Modification Is Reduced in People With Poststroke Foot Drop Using an Ankle-Foot Orthosis[J]. Physical Therapy . 2014 (5)

[6] Cakar F, Durmus O, Tekin L, Dincer U, Kiralp MZ. The ankle-foot orthosis improves balance and reduces fall risk of chronic spastic hemiparetic patients. Eur J PhysRehabil Med 2010；46.3：363-8.

[7] Ridgewell E, Dobson F, Bach T, Baker R. A systematic review to determine best practice reporting guidelines for AFO interventions in studies involving children with cerebral palsy. Prosthet Orthot Int 2010;34:129~?5.

[8] Bregman D J J. The Optimal Ankle Foot Orthosis: The influence of mechanical properties of Ankle Foot Orthoses on the walking ability of patients with central neurological disorders[J]. Amsterdam Vrije Universiteit, 2011.

[9] Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. Lancet Neurol.2009;8(8):741-754.

[10] Leung J, Moseley A. Impact of Ankle-foot Orthoses on Gait and Leg Muscle Activity in Adults with Hemiplegia : Systematic literature review[J]. Physiotherapy, 2003, 89(1):39-55.

[11] Faustini M C, Neptune R R, Crawford R H, et al. Manufacture of Passive Dynamic ankle-foot orthoses using selective laser sintering.[J]. Biomedical Engineering IEEE Transactions on, 2008, 55(2Pt1):784-790.

[12] Radtka S A, Skinner S R, Dixon D M, et al. A comparison of gait with solid, dynamic, and no ankle-foot orthoses in children with spastic cerebral palsy.[J]. Gait & Posture, 2005, 21(3):303-10.

[13] Zhao Zhengquan Su Jiang, Han Lin. The analysis of the side effects of brace and prevention [J]. Chinese journal of physical medicine and rehabilitation, 2006, 28 (12) : 847-848.

[14] Shelburne K B, Torry M R, Steadman J R, et al. Effects of foot orthoses and valgus bracing on the knee adduction moment and medial joint load during gait.[J]. Clinical Biomechanics, 2008, 23(6):814-21.

[15] Romkes J, Brunner R. Comparison of a dynamic and a hinged ankle-foot orthosis by gait analysis in patients with hemiplegic cerebral palsy. Gait Posture. 2002;15:18-24.

[16] Danielsson A, Willen C, Sunnerhagen KS. Measurement of energy cost by the physiological cost index in walking after stroke. Archives of Physical Medicine and Rehabilitation . 2007

[17] Xiong Baolin, Zhou Dawai, Xu Jing. The impact of lower limb muscle fatigue with plastic ankle foot orthoses [J]. Chinese Journal of Tissue Engineering Research, 2014 (25) : 4095-4100.

[18] Zollo L, Zaccheddu N, Ciancio A L, et al. Comparative analysis and quantitative evaluation of ankle-foot orthoses for foot drop in chronic hemiparetic patients[J]. European Journal of Physical & Rehabilitation Medicine, 2014, 51(2).

[19] Damme B V, Stevens V, Tiggelen D V, et al. Performance based on sEMG activity is related to psychosocial components: Differences between back and abdominal endurance tests[J]. Journal of Electromyography & Kinesiology, 2014, 24(5):636-644.

[20] Dario F, Roberto M, Enoka R M. The extraction of neural strategies from the surface EMG.[J]. Journal of Applied Physiology, 2004, 96(4):1486-1495.

[21] Donald·A. Neumann.2014.Kinesiology of the Musculoskeletal System Foundations for Rehabilitation[M](in Chinese). People's Military Medical Press

[22] Rodriguez-Falces J, Neyroud D, Place N. Influence of inter-electrode distance, contraction type, and muscle on the relationship between the sEMG power spectrum and contraction force.[J]. European Journal of Applied Physiology, 2014, 115(3):627-638.

[23] Tello R M G, Bastos-Filho T, Costa R M, et al. Towards semg classification based on Bayesian and k-NN to control a prosthetic hand[C]// Biosignals and Biorobotics Conference (BRC), 2013 ISSNIP. IEEE, 2013:1-6.

[24] Zhang Jinhua Wang Yuxia, Yang Zheng, et al. Dynamic and static ankle foot orthoses on spastic type cerebral palsy children curative effect comparison [J]. Chinese journal of rehabilitation medicine, 2009, 24 (1) : 45-48.

[25] Ferris DP, Czerniecki JM, Hannaford B. An ankle-foot orthosis powered by artificial pneumatic muscles. J ApplBiomech.2005; 21(2):189-197.

[26] Gordon K E, Sawicki G S, Ferris D P. Mechanical performance of artificial pneumatic muscles to power an ankle-foot orthosis.[J]. Journal of Biomechanics, 2006, 39(10):1832-1841