MOVEMENT, TORQUE AND SUBJECTIVE PAIN BY ELECTRICAL STIMULATION IN ANKLE PLANTARFLEXION

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The aim of this study was the investigation of the dynamical movement of the ankle plantarflexion and subjective pain by electrical stimulation, which are considered as key points to improve the walking performance effectively, and to make users more comfortable. These results apply for developing assisting walking devices for elderly people and improving the performance of FES walking system for hemiplegia patients. The results shows that the ankle movement and generated torque are strongly depend on the pulse width of stimulation. The increase of stimulating frequency generates better movements, but the subjective pain increase proportionally. From the results in this paper, the stimulating frequency f=30Hz and the pulse width W=0.9ms is one of balanced choice to achieve the less pain and the better movement of ankle by the electrical stimulation.

Key words: ankle plantar flexion, ankle torque, subjective pain, electrical stimulation

1. Introduction

Increased gait variability by slow walking speed predicts future fall risks. Slow walking in elderly people [1] and stroke patients [2] is well known. Slow walkers such as elderly people and stroke patient have a possibility of hip fracture caused by side fall, because the body in side fall is difficult to be supported by hands, so the hip crashes to the ground in many cases. The slow walking is one of causes of side fall is reported. [3] So walking speed has a important role to keep the stability of walking because the kinetic energy to the front, which reduces side movements, increases along with the walking speed.

Ankle plantar flexor by gastrocnemius and soleus muscle is very important to increase walking speed. Weakness of ankle plantar flexor should be considered as one factor of slow walking in elderly [4] and stroke patients. [2, 5] Also the results of dynamic simulation of normal walking show that the ankle plantarflexion by gastrocnemius and soleus well contribute to increase the forward progression of the trunk. [6] The FES walking system for hemiplegia patients focused on preventing the foot-drop by stimulating Dorsiflexion muscles in swing period. A Recent study to aim at improving the FES walking system delivered to the ankle plantarflexion and dorsiflexion [7] shows that the average contribution of the paretic leg increases 33.1% from 28.8% without FES, but there is no difference between dorsiflexion with plantarflexion and dorsiflexion only, though the ankle plantarflexion is important for walking.

The aim of this study was to investigate the dynamical movement and generated torque with subjective pain by electrical stimulation in the ankle plantarflexion, which are considered as key points to improve the walking performance effectively and to make users more comfortable. These results apply for developing assisting walking devices for elderly people and improving the performance of FES walking systems for hemiplegia patients.

2. Methods

Experiment

The Figure 1 shows the experimental device to measure movement and torque by electrical stimulation in ankle. The device was designed for measuring the angle of ankle movement with resistant load torque. The subject lied down on the right side and the subject's right foot was fixed to the bottom plate with rubber band and the plate rotated the axis correspond to the ankle rotational axis. Also the large pulley (radius 300mm) was fixed the bottom plate and the vertical weight load via wire string with small pulley acted against the ankle

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rotation. The weight Mkg and large pulley radius 300mm determined the load torque. The bottom plate under a feet was designed much lighter weight than a foot weight, so we assumed the effect of rotating inertia of the device can be neglected. The subjects in experiments were lie on the right side to prevent from the mass effect of the plate by gravity. The potentiometer dynamically detected the angle of subject's ankle. The electrical stimulation of ankle plantarflexion muscles was done via self-glued surface electrodes. The size of the surface electrode for both anode and cathode electrodes are 50mm by 80mm. The cathode electrode is adhered on the top end of the medial and lateral gastrocnemius muscles. The anode electrode was on the bottom end of gastrocnemius muscles. The monophasic and rectangular pulse wave in electrical stimulation was employed for this experiments, because the stimulation with monophasic and rectangular shape are the most effective from experimental results.[8] The pulse generated by the stimulator is amplified by the isolation amplifier. The recording of ankle measurement was carried out with sampling frequency 100Hz. A trigger at each trial started the recording and the electrical stimulation synchronously.

Procedure

Two load conditions were tested. One is no load, and another is 5Nm resistant torque. The initial position of weight was on the floor at the ankle angle is 0deg. The pulse interval D and width W were randomly chosen from 20ms (50Hz), 33ms (30Hz) and 50ms (20Hz) at the D and from 0.1ms to 1.3ms at the W. The current C of the pulse was fixed at 20mA. The subjective pain at each trial was assessed by the Revised Face Pain Scale (FPS-R) [9]. The subject lied on the right side on the device and the right leg in all subject were tested. Initial ankle position at each trial is 0deg, which means that the angle between the bottom surface of foot and the longitudinal axis of lower leg is 90deg. Each trials start by a trigger, which also start electrical stimulation and recording dynamic movement of ankle's angle. The stimulations continue one second, and then the hearings of the subjective pain were done.

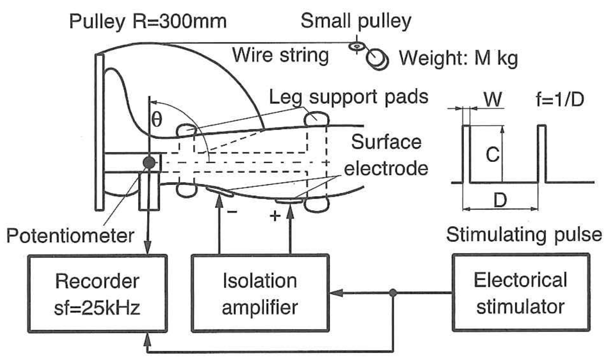

Fig.1 Experimental device

Methodology for estimating ankle torque

The torque of ankle joint is described by Eq. (1) with the assumption that the inertia moment of large pulley and the bottom plate was neglected.

$$T \;@\; MR^2\ddot{t} \;.\; RMg \qquad (1)$$

Before the torque estimation with Eq. (1), the noise signals in the recording data were smoothed by the 1st order lowpass filter, which cut off frequency is 5Hz.

Subject

Two healthy subjects joined this study. The descriptions of subjects are on Table 1. The subjects were well informed this study and made consents before experiments. The results of the subject A and B were similar, so we show the subject A's results as typical type of results.

Table 1 Subject specification

Subject	A	B
Age	20	20
Height [cm]	169	169
Weight [kg]	52	56
Sports activity	Occasionally	Occasionally

3. Results and Discussion

The Figure 2 shows typical dynamic ankle movement and estimated ankle torque in subject A with the condition the frequency f=30Hz(D=33ms) and the pulse width W=0.9ms. This graph shows from the stimulation start by a trigger to the time at the maximum angular velocity of ankle plantarflexion. The estimated torque at the load 5Nm rose sharply at the beginning in the ankle movement, and then the angular velocity

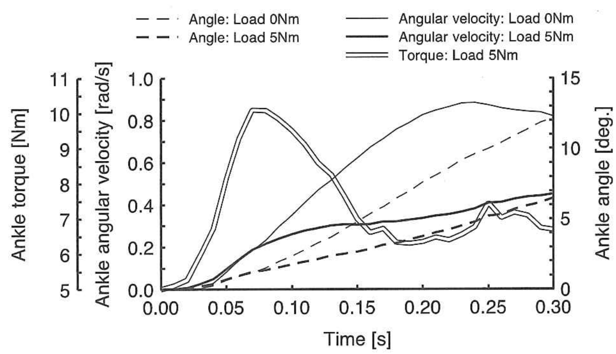

Fig. 2 Time response of ankle movement

generated, and then the angle movement began. In this experiment procedure, the ankle did not support the weight at the initial position, because the weigh was contacted on the ground. So the estimated torque has an offset 5Nm in all times. In the comparison between no load and 5Nm load, the movements on both cases were the similar until 0.75s, but the movement on no load became faster than on 5Nm load gradually. We focus on the typical six points in the time response by the stimulating frequency f and the pulse width W; the maximum angular velocity, the time at maximum angular velocity, the ankle angle at maximum angular velocity, the maximum torque and the time at maximum torque.

The figure 3 shows the maximum angular velocity by the pulse width W. The figure 4 shows the time at the maximum angular velocity. The increase W gave the faster plantarflexion on both load conditions, but the movements on no load were faster than on 5Nm load. Because the part of the ankle torque is used to pull the weight up. The difference in frequencies was smaller than the effect on the pulse width, but the higher f gave the faster movements. About the time at the maximum velocity, the values were constant in the case that the W was greater equal than 0.9ms. In the W<0.9ms, the ankle movements were not stable in this subject A's case. All cases in the stimulating frequency were similar and constant around 0.3s on the W≥0.9ms. The time in 5Nm load were faster 0.05s than the time in no load on the W≥0.9ms. The figure 5 shows the ankle angle at the maximum angular velocity. This results showed the same tendency in the maximum angular velocity of the figure 3. The times at maximum angular velocity in various conditions were almost the same, so the conditions to give fast movements in angular velocity showed large

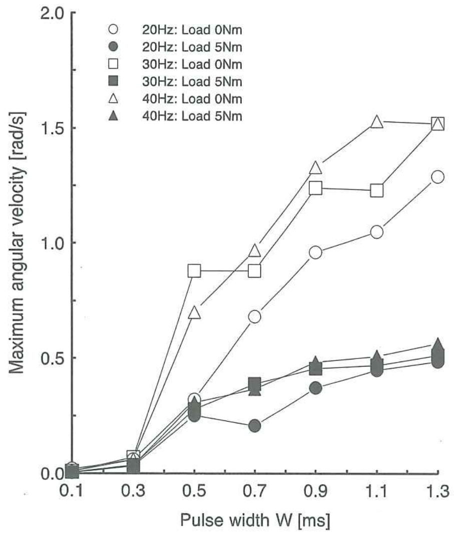

Fig. 3 Maximum angular velocity of ankle movement

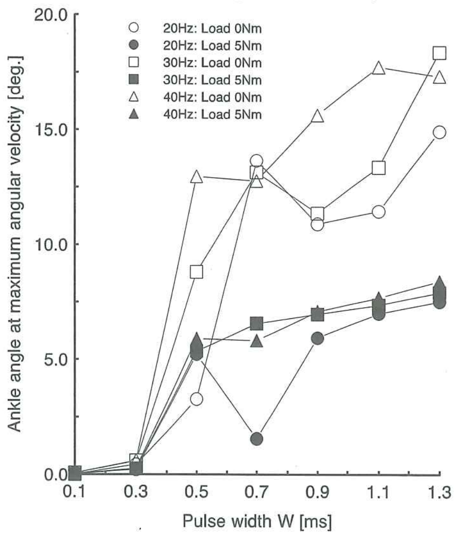

Fig. 5 Ankle angle at maximum angular velocity of ankle movement

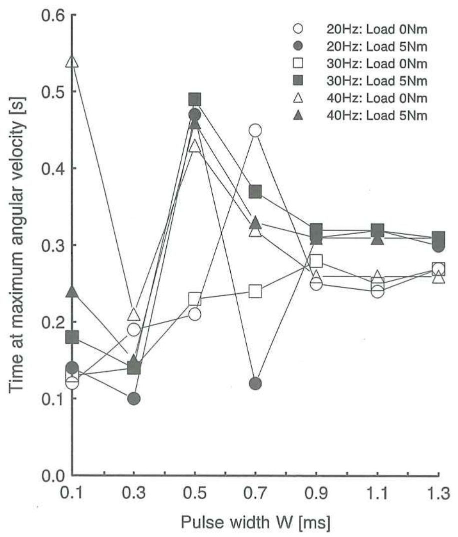

Fig. 4 Time at maximum angular velocity of ankle movement

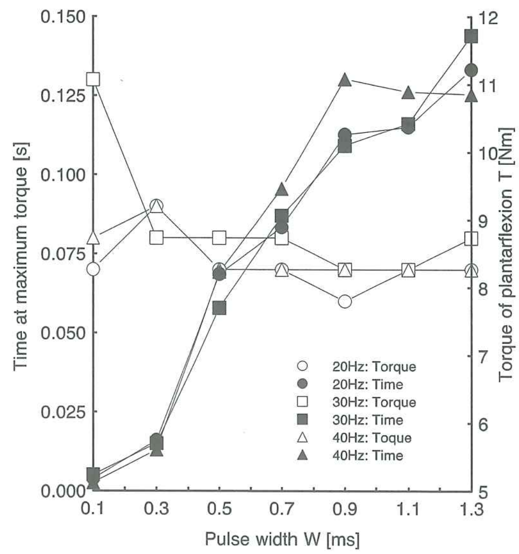

Fig. 6 Torque of plantarflexion

movements in ankle angle.

The figure 6 shows the estimated ankle torque on the 5Nm load. The maximum generated torque by electrical stimulation increased over 10Nm in the W≥0.9ms. The increase of the W generated the large torque T proportionally, but the maximum torque roughly saturated over W =0.9ms. The time at the maximum torque were constant around 0.075s on the W≥0.5ms. The differences in stimulating frequencies are almost nothing.

The figure 7 shows the subjective pain on various conditions. The subjective pain 100 is unbearable pain in the subject. The increase W caused the proportional rises of the subjective pain. Also the increase of the stimulating frequency and load torque raised the subjective pain proportionally. This remarkable difference between the subjective pain and the movement is very important, because we should select the stimulating condition with less pain and better movement to apply FES systems to human. From the results, the stimulating frequency f=30Hz and the pulse width W=0.9ms is one of balanced choice to achieve the less pain and the better movement of ankle by the electrical stimulation.

4. Conclusions

The aim of this study was to investigate the dynamical movement and generated torque with subjective pain by electrical stimulation in the ankle plantarflexion. The results shows that the ankle movement and generated torque are strongly depend on the pulse width of stimulation. The increase of stimulating frequency generates better movements, but the subjective pain increase proportionally. From the results in this paper, the stimulating frequency f=30Hz and the pulse width W=0.9ms is one of balanced choice to achieve the less pain and the better movement of ankle by the electrical stimulation.

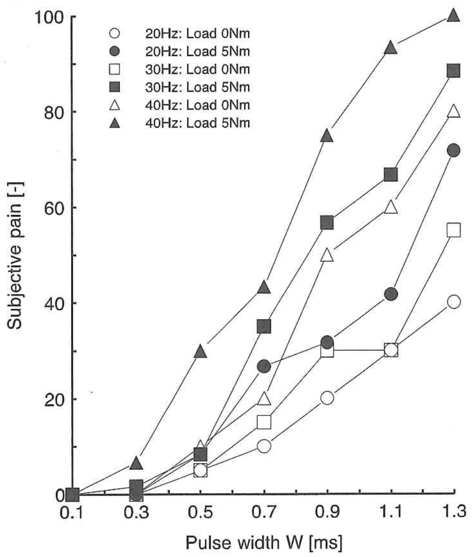

Fig. 7 Subjective pain

5. Acknowledgements

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