Clinical application of acceleration sensor to detect the FES assisted swing-through gait cycle

Matsunaga T 1, Shimada Y 1, Sato M 1, Chida S 1, Hatakeyama K 1, Misawa A 2, Shirahata T 2, Takeshima M 2, Iwami T 3, Miyawaki K 4, Iizuka K 5

1 Rehabilitation Division, Akita University Hospital, 1-1-1 Hondo, Akita, 010-8543 JAPAN
2 Division of Orthopedic Surgery, Department of Neuro and Locomotor Science, Akita University School of Medicine
3 Department of Mechanical Engineering, Akita University Faculty of Engineering and resource Science
4 Akita Prefectural Industrial Technology Center
5 BIOTEC, Ltd

E-mail: matsu@med.akita-u.ac.jp

Abstract

The purpose of this study was to evaluate the possibility of detecting swing-through gait cycle using an accelerometer and a machine learning technique (Neural Network). Two non-disabled adult males volunteered for this study. One 2-axis accelerometer, heel sensor and infrared rays sensor were used for the sensors. For Neural Network training, acceleration data was processed with the input data, and the infrared rays data and heel data were processed with the target data. The microcomputer produced output signals using the Neural Network program. The accuracy of the microcomputer output data was compared with the motion analysis data. The Neural Network detector could correspondingly detect predict the beginning of gait cycles. The present system has a potential to access the reconstruction of FES assisted swing-through gait with free-knees in paraplegic patient.

1. INTRODUCTION

The inability to stand and walk often constitutes a severe handicap for a paraplegic patient in the community in spite of environmental modifications such as improved wheelchair access to buildings. The swing-through gait is a fast and effective gait pattern for paraplegic patient who are able to perform it. Several authors reported swing-through gait is mostly adopted to help locomotion for paraplegic patient [1, 2]. Heller and colleagues first reported the clinical study of functional electrical stimulation (FES) assisted swing-through gait with free-knees, and concluded that it is shown to be a potentially useful mode of FES gait [3].

For the successful reconstruction of FES assisted swing-through gait, it is important to detect gait cycle and stimulate lower limb muscles adequately. There are several sensors to detect gait cycle such as heel sensors, tilt sensors, gyroscopes, etc. There is also a possibility of detecting a gait cycle using an acceleration sensor and a machine learning technique (Neural Network). The purpose of this study was to evaluate the possibility of detecting swing-through gait cycles using an accelerometer and a machine learning technique (Neural Network).

2. METHODS

2.1 Subjects

Two non-disabled adult males volunteered for this study. The subject details are given below:

Subject A: 23 years, 163 cm, 53 kg.
Subject B: 55 years, 168 cm, 70 kg.

The subjects had no previous disease or injuries to their musculoskeletal systems. Prior to the study, each subject had undergone the swing-through gait training using axillary crutches. Written informed consent was obtained in this study.

2.2 Experimental settings

In this study, we focused on the possibility of detecting the mid body swing phase (Figure 1-A) and heel off (Figure 1-B) in the gait cycles for the appropriate stimulation of knee extensors. One 2-axis accelerometer (ADXL 202: Analog Devices, Inc., Tokyo, JAPAN), one heel sensor (Click BPG, Tokyo Sensor, Inc., Tokyo, JAPAN) and one infrared rays sensor (GP2D12: SHARP, Inc., Osaka, JAPAN) were used for the detection of swing-through gait.
cycles. The acceleration sensor was mounted on the ADXL 202 evaluation board and positioned on right side of the axillary crutch. We measured changes in acceleration during swing-through gait in the sagittal and gravitational directions of the crutch (Figure 1-a). The infrared rays sensor was placed on right side of the axillary crutch to detect the body swing through the crutches in the gait cycle (Figure 1-b). The heel sensor was placed under the heel on the right side to provide reference points for the heel off in the gait cycle (Figure 1-c). The signals were recorded using a ND-2000 recorder (KEYENCE, Inc., Osaka, JAPAN).

Subjects A walked barefoot on the laboratory floor by swing-through gait using axillary crutches without any braces. The data from sensors were input to a personal computer, and was processed using a learning form. For Neural Network training, the acceleration data was processed with the input data (Figure 1-a), and the infrared rays data and heel data were processed with the target data (Figure 1-b and c). We calculated bias and weight of the Neural Network using MATLAB (Cybernet System, Inc., Tokyo, JAPAN) and the Neural Network Toolbox (The MathWorks, Inc., Natick, MA, USA). We wrote a Neural Network program including weight and bias, using the computer programming language C, and forwarded the program to a microcomputer (H8/3048F: HITACHI, Inc., Tokyo, JAPAN). The microcomputer produced output signals using the Neural Network program, in real time (Figure 1-d).

Figure 1. Target events during swing-through gait (A, B), sensor signals (a, b, c) and output signal (d)

2. 3 Assessment of detecting the gait cycles

The accuracy of the microcomputer output data was compared with the motion analysis data. Subjects were performed swing-through gait using axillary crutches on the laboratory floor. Kinematic data of the gait was recorded by using computer video-based integrated three-dimensional system for human motion analysis (Peak Motus® Motion Measurement Systems, Peak Performance Technologies, Inc., USA). Prior to data acquisition, reflective markers were placed on fifteen anatomical locations on the subjects as follows: bilateral positions of the shoulder, elbow, hip, knee, ankle, and foot. An additional marker was placed on the neck (C7 level) and the bilateral axillary crutch tips. The ground reaction forces of the foot and axillary crutch during locomotion were monitored by three Kistler force platforms (Kistler force plate 9281B, Kistler Instruments AG, Switzerland).

3. RESULTS

In subject A, the Neural Network detector was able to detect the body late-swing phase and heel off (Figure 2).

In subject B, the Neural Network detector was able to detect the heel off. However, there was a difference in the timing between the mid body-swing phase and the output signal (Figure 3).

4. DISCUSSION AND CONCLUSIONS

A variety of sensors have been studied for use in FES [4, 5]. In the present study, an acceleration sensor and a Neural Network were used to detect swing-through gait cycles, and to reduce the maximum difference in timing of the stimulation. We were able to detect the swing-through gait cycles using only an acceleration sensor and the Neural Network. The Neural Network detector could correspondingly detect the beginning of gait cycles in Subject A. On the other hand, in Subject B, whose output signal was produced from input and target data in Subject A, there was a difference in the timing between the mid body-swing phase and the output signal. The present findings suggest that the suitable output signal is in need of the input and target data from target subject.

In some cases, FES has been used to maintain the knees locked in extension throughout the
gait cycle in the reconstruction of FES assisted swing-through gait. This method emulates the role of long leg braces and is still expensive in energy cost. FES assisted swing-through gait with knee free is adequate for reducing this energy cost. The present system (an acceleration sensor and the Neural Network) has a potential to access the reconstruction of FES assisted swing-through gait with free-knees in paraplegic patient.

References


**Figure 2.** Stick picture and output signals of Subject A

**Figure 3.** Stick picture and output signals of Subject B