1 Introduction

According to Basmajian (Basmajian, 1981) 'Modern biofeedback is the technique of using electronic equipment to reveal instantaneously to patients and therapists certain physiologic events and to teach the patients to control these otherwise involuntary events by manipulating the displayed signals (usually visual and/or acoustic)'.

Biofeedback training techniques are increasingly used in rehabilitation medicine for the treatment of many varied disorders. The most usual biofeedback techniques supply information on muscle contraction (EMG feedback) in the muscle re-education of patients with central nervous diseases (e.g. strokes, lesion of the basal ganglia) or central nervous system trauma (spinal cord or head trauma) (Basmajian, 1981). However, in locomotion impairments in addition to techniques based on EMG biofeedback, those techniques supplying knowledge of body movements during walking are increasingly used.

Different transducers have been used to obtain such information; joint angle detectors (Hogue and McAndless, 1983; Colborne and Olney, 1990), force transducers (Warren and Lehmann, 1975; Craik and Wannstedt, 1975; Wannstedt and Hermann, 1978; Seeger et al., 1981) or contact switches signalling foot placement (Spearing and Poppen, 1974). So far, only one system, proposed by Hirokawa and Matsumura (Hirokawa and Matsumura, 1989), provides general information on the efficiency of the patient's locomotion. In their biofeedback gait training system, Hirokawa and Matsumura attached importance to the concept that such training should be carried out at a prescribed walking velocity, imposing on the subject the length of the step and the duration of stride. For that purpose, they built a walker moving at the prescribed velocity that the subjects had to follow. An instrumented walkway was used for measuring the distance and temporal factors of gait, and for triggering visual and audio feedback signals delivered by CRT monitor and a buzzer mounted on the walker.

Simultaneous processing of spatial and temporal biofeedback probably makes the locomotion task more difficult to perform than when only one type of biofeedback has to be taken into account. Experimental neurosis may be induced by too complex biofeedback training system (Bilodeau, 1966), particularly during rehabilitation of the central nervous pathology (hemiparesis for example).

Consequently, it seemed better to begin the biofeedback training programme by focusing the subject's attention on only one walking parameter and to offer a simple task so that the biofeedback training became easy to understand. The step length was chosen, with the hypothesis that correcting spatial gait asymmetry would lead to a general improvement of motor coordination and performance, and...
consequently of the temporal parameters. Indeed, a relationship does exist, at least in normal subjects, between the step length and the stride duration (MURRAY, 1967; LARSSON et al., 1980).

We propose a biofeedback gait training system for left and right step length, adapted to the correction of spatial walking asymmetries by means of a simple, quick and reliable method, for daily clinical use without interfering directly with the temporal organisation of the walking cycle. The step length is imposed on the subject by means of lighted targets appearing on a walkway, alternately on the right and left sides.

2 Method

The feedback set-up (Fig. 1) includes a walkway and a gait analysis device (locometer) linked to a micro-computer for walkway command, data acquisition, processing and storage.

2.1 Locometer

The locometer has been described fully elsewhere (BESSOU et al., 1989). It is composed of two identical devices, allowing recordings of the longitudinal displacements of both feet to be made by linking each foot to a length-voltage transducer, a potentiometer, by means of threads. It has two purposes; to determine the position of each foot with respect to the starting line, in order to compare the foot position with the target position; and to evaluate the efficiency of locomotion by measuring the main spatial and temporal parameters of the walking cycle. The values were measured with a resolution of ±1 cm for the lengths and ±10 ms for the durations.

The analogue electrical signals from the two potentiometers (one for each foot) proportional to the distances covered by the feet from the starting line were sent through an A/D convertor to a micro-computer.

2.2 Lighted walkway

The aim was to make the subject take steps of a given length. This was done by triggering the lighting of targets in appropriate positions along the walkway and the subject having to place a swinging foot on the lighted target. The walkway (Fig. 1) (7.2 m long and 1.5 m wide) was made of wooden floorboards with two parallel rows of 642 light-emitting diodes (LEDs). The diodes (one cm apart) were built into the wood and covered with transparent Plexiglas plates. The LED rows were 6.4 m long. Each row was divided into six models of 107 LEDs with an electronic command card. The 12 cards were interconnected to a master card controlled by the micro-computer. The target was formed by lighting a number of successive LEDs so that its length was the subject's foot size; it appeared alternately on the right and on the left, showing the place where the subject had to set the foot.

2.3 Functional organisation of the step length biofeedback device

The apparatus was organised (Fig. 2) around a PC-AT IBM-compatible micro-computer* connected to several peripheral units (keyboard, monitor, printer, plotter, loudspeaker and two removable hard disks for mass memory). The analogue signals (±10 V) from the two potentiometers were sent through an analogue/digital card+ to the PC. The A/D conversion resolution was 12 bits (4096 counts) with a conversion duration of 15 μs. The sample frequency of the signals was 100 Hz. The PC controlled the lighting of the LEDs on the walkway through a command card designed for this application.

2.4 Software

The software, written in Turbopascal, allowed initial calibration, testing of the connections to the walkway, acquisition of the signals, and subsequent analysis of the collected data. The programs (all menu-driven) allowed visualisation and printing of the simultaneous horizontal displacements of the two feet versus time, and detection of the beginning and the end of the phases of the locomotor cycle. They also allowed the computation and printing of the different spatio-temporal parameters of the gait and the results (errors, number of trials etc.) of the biofeedback session.

The main program consisted of a routine allowing, after storage of patient information, the selection of the following parameters: the starting foot, the foot size, the left step and the right step lengths with the accepted error (±5% of the step length in the present study).

The program started by lighting the two targets under the feet at the starting line. By pressing any key, the target moves forward by the step length programmed. The subject...