WALKWAY SYSTEM FOR MEASURING AND TRAINING IN GAIT

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Abstract: We developed a biofeedback gait training system; a 12 m measuring walkway with a training walker which moves at prescribed velocity. The walkway measures all temporal and distance factors of gait. This system provides visual feedback for distance factors and auditory one for temporal at the prescribed walking velocity. Experiments were performed on normal and degenerative knee joint subjects, and this system was verified to be very useful.

1. Introduction

Although the concept of biofeedback training has now been accepted and various devices for providing biofeedback have been proposed in the field of gait analysis /1,2,3,4/. Only a few devices have been available for daily clinical use. There are three main reasons for this unavailability:
First, the absence of accompanying read-out equipment, so, additional one must be used jointly to evaluate their effects.
Secondly, training devices have not sufficient length for many steps.
Finally, the most important concept - the gait training should be carried under the prescribed walking velocity - has been neglected. As gait patterns vary with walking velocities /5,6,7/, the training with the prescribing velocity is neccesary.

It may be wise for biofeedback gait training to use discrete gait parameters - distance and temporal factors of foot-floor contact. Since a gait is one of typical stochastic phenomena, while very complex, different and variable between- and within-individual.
Combining several method can derive abundant and detailed analogous information. However, the more become so, the more complex to evaluate its clinical status, the more expensive to be applied prevalently, and the more difficult from the hardware viewpoint to supplement a certain feedback system.

The authors have developed a biofeedback gait training system, composed of a 12-m-measuring walkway /3/ and a training walker which moves at the prescribed velocity.
This system provides audible feedback for temporal factors of gait and visible feedback for distance factors. The advantage of this system is that it can deal with the gait problems of all subjects in any phase of rehabilitation: measurement, analysis, training, and/or evaluation.
Using this system, experiments were performed about:

1) Asymmetrical biofeedback to normal subjects,
2) Biofeedback gait training to degenerative knee patients.

2. SYSTEM

2.1 A measuring walkway and a training walker.

A measuring system is constructed by several instrumented walkway-units for a signal acquisition and a micro-computer for data processing and record. Data acquisition and analysis can be done by a simple procedure: subject must only walk twelve meters with arbitrary shoes or bare feet without any additional restriction. An unit-walkway is a 10 mm x 10 mm wire-latticed board 1.28 ms long and 0.9 ms wide, made possible to be connected with each other, so demanded length can be available, typically 12 ms for adult.

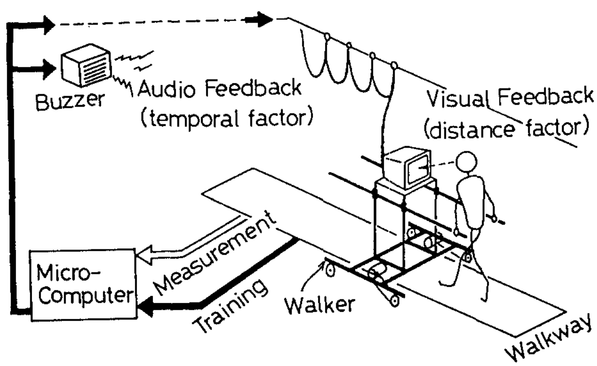

Fig. 1 Schematic drawing of the system: a walkway for measuring temporal and distance factors and a walker for prescribing velocity and helping trainee.

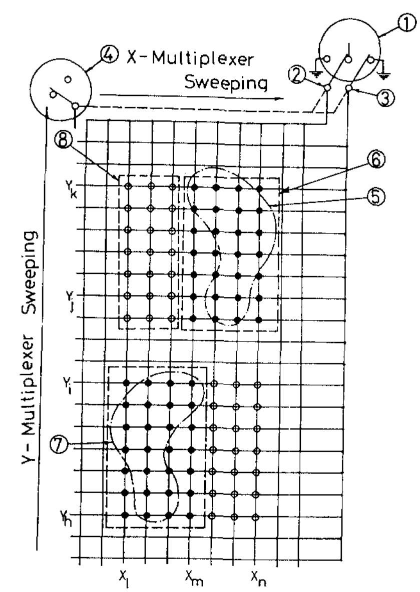

Fig. 2 Principle of detecting foot positions on the walkway.

The wires were passed through urethane mat which has punched out round circles of 7 mm diameter for each lattice. The crossing x- and y-axis wires were separated by 3 mm vertical distance and come into contact with each other by a foot stamp over 24500 Pa pressure.
The foot stamp positions are detected electrically as wire-cross points. For example, if one of the x-axis wires makes contact with some of the y-axis wires, the contacting y-axis wires are easily identified from the currents, derived from the x-axis wire. Its temporal shift are traced by switching over sweeping area for electric currents. The sweeping frequency can vary from 10 to 100 Hz for adjusting individual walking velocity. These are performed by digital multiplexers and demultiplexers, comparators and a crystal oscillator.

Then, these data are sent to a micro-computer. The micro-computer calculates all of the temporal and distance factors of gait: single and double limb support durations, walking velocity, step length and width, and foot angle. A real foot stamp pattern 3 in Fig.2 is formed from square shaped pattern 4 and a dummy area 6 in double support duration by a special algorism. This algorism is constructed from discriminant logic between single and double support phases, previously reported /8/. Foot angle is calculated by a linear interpolation, derived from the regression analysis.

The walker has two parallel grasping bars and a monitor-CRT for biofeedback of distance factors. The grasping bars act as a therapist would in helping a serious pathological patient. Its dimensions are 1.21 m length, 1.24 m width and 1.3 m hight, and it weighs 65 Kgs. The setting height of CRT and grasping bars are adjustable to fit each trainee's body height.

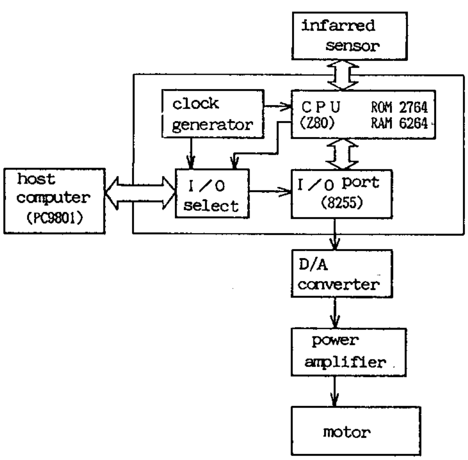

Fig. 3 Walker driving system.

This walker is controlled by an built-in micro-computer and driven by the servo-motors. This moves at the prescribed velocity and stops automatically at the walkway edge, like " a line trace mouse" with sensors which detect the reflected light from silver-tape on the center of the walkway. Velocity of the walker is variable for a trainee from 12 to 180 meters per minute.

2.2 Biofeedback of distance factors

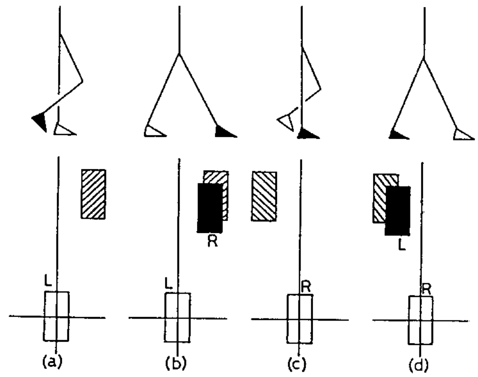

Fig. 4 Biofeedback of distance factor on the monitor display.

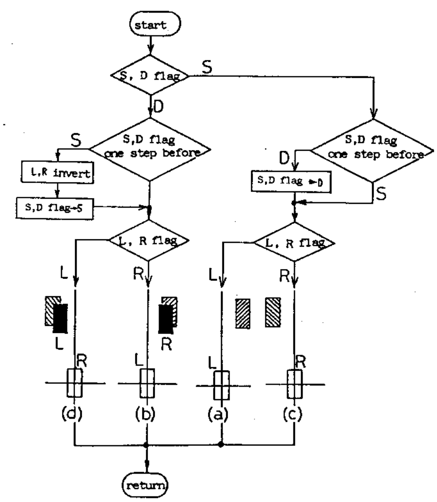

Fig. 5 Algorismic flowchart for displaying the distance factor

On the CRT, the trainee is informed of the difference between the desired and actual foot stamp positions at each step in the following manner: First, it establishes the position of the center of the supporting foot (hollow-square in Fig. 4) as the origin, the desired foot stamp position for the next step (slashed-square) is displayed and then the succeeding actual one (solid-square) is overlaid. The trainee, then, should make efforts only to overlap slashed and solid ones on the CRT.

2.3 Biofeedback of temporal factors

The desired temporal factors are indicated by the tone of the buzzer sound.
The desired temporal factors are indicated to trainee by the three different tones of the buzzer sound, according to his/her condition. For example, a left-single support duration in a certain walking cycle is graded by three conditions as compared with the desired one, and the sound of the respective tone is played at the next left-single support duration.

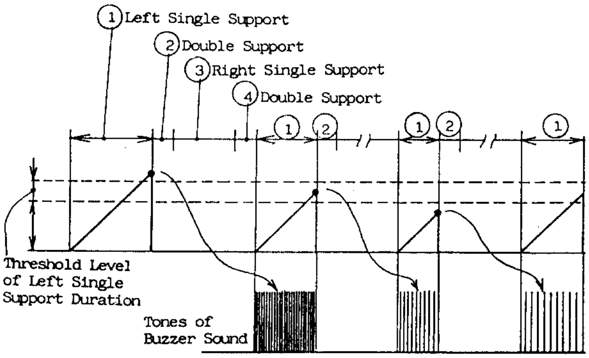

Fig.6 Biofeedback of temporal factors by the tones of the buzzer sound.

3. EXPERIMENT AND RESULTS

In order to verify the validities of our biofeedback gait training system, one normal subject and three patients of degenerative knee joints were examined.

3.1 Asymmetrical gait to normal subject

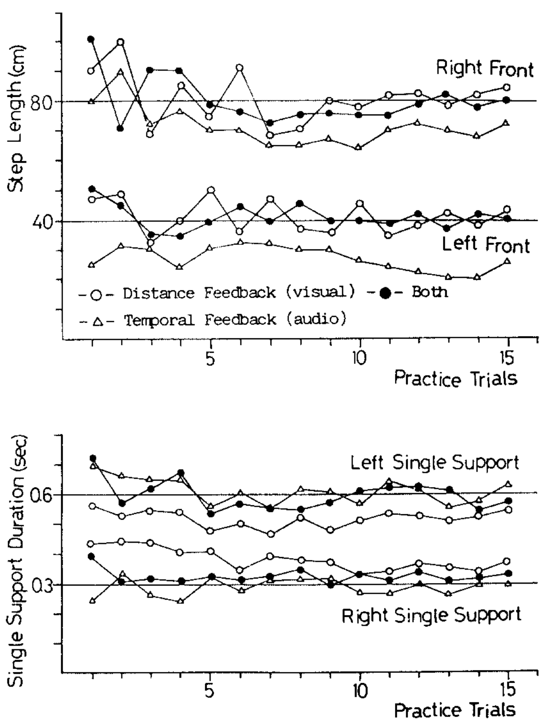

Fig. 7 Asymmetrical gait training for the normal subject.

Normal subjects made walk asymmetrically. Feedback was settled so that the step lengths and the single support durations of the left and the right were in the ratio of 1 to 2. The feedback was provided in three ways, namely, the visual (hollow circle in Fig.7) or the audio feedback alone (triangle), and the both feedback jointly (solid circle).

These diagrams show mean values of respective variables in each trials.
The subject learned asymmetrical gait not later than ten times through biofeedback information.
The visible feedback for distance factors was more effective than the auditory one for temporal.
There were additive effects by combined use of visible and auditory biofeedback , because both are provided well coordinatelly.

3.2 Biofeedback training of knee osteo-arthritis patients

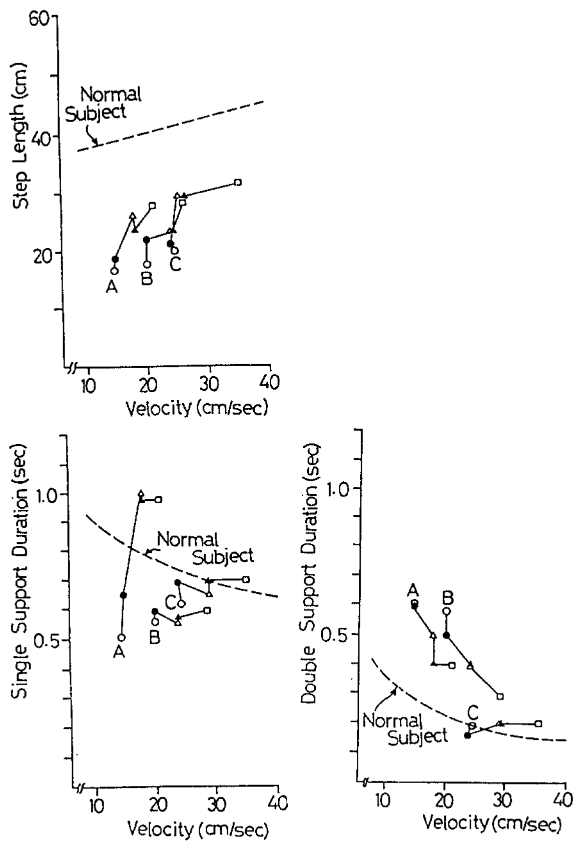

Fig. 8 Biofeedback training to knee osteo-arthritis patients.

An experimental study was performed on three degenerative knee joint patients (one female- 78 years, two males - 41 and 75 years).
As for patients of degenerative knee joint, they were ordered to walk with longer step length and shorter double support duration than those at their present gaits.
Each subject was instructed to walk twice in the following five ways:

(1) free walking without using the walker (hollow circle in Fig. 8)*,
(2) following the walker but not grasping the parallel bars (solid circle),
(3) walking with grasping the bars at the free-walking velocity (hollow triangle)*,
(4) walking with grasping the bars at the free-walking velocity (solid triangle),
(5) at a speed with a 20 % increase in velocity (square),

where the mark * means the case without feedback

information.
The chained line in Fig.8 is the mean value of the gaits of 92 normal college students /8/. Data were plotted in relation to walking velocity. When they walked with grasping the parallel bars, their pathological gaits were improved remarkably. Without grasping the parallel bars, the feedback information seems not to be so effectual, however, it is proved to be effective in the following Table 1.

Table 1. Coefficient of variation in Fig. 8

< a > Step Length

	(1)	(2)	(3)	(4)	(5)
A	0. 11	0. 04	0. 06	0. 04	0. 07
B	0. 08	0. 10	0. 11	0. 06	0. 06
C	0. 05	0. 07	0. 08	0. 05	0. 10

< b > Single Support Duration

	(1)	(2)	(3)	(4)	(5)
A	0. 18	0. 10	0. 09	0. 05	0. 06
B	0. 10	0. 08	0. 08	0. 06	0. 09
C	0. 13	0. 13	0. 09	0. 08	0. 10

< c > Double Support Duration

	(1)	(2)	(3)	(4)	(5)
A	0. 13	0. 09	0. 14	0. 05	0. 20
B	0. 09	0. 11	0. 19	0. 14	0. 19
C	0. 12	0. 09	0. 11	0. 12	0. 17

The coefficients of variation in the condition (4) are smaller than those in (3), which indicates that, the feedback information in condition (4) is utilized effectively.
Faster walking in condition (5) makes larger coefficients of variation than condition (4).

4. Discussion

This quantitative statistical analysis is important, not only for normal gait but also pathological one, since all gait parameters of pathological subjects are more or less deviated from normal range about variation and symmetricity, and the level and interrelation of their deviation is the most important information for evaluating pathological gait.
The forte of our system is to do training in a total rehabilitative circulation: namely, measurement, analysis, training and evaluation.
Therefore, one may conclude that the strategy for gait improvement should be to repeat the training under conditions (3) and (4) for a sufficient time and then switch to condition (2) to complete the rehabilitation.

The advantages of our system are,
a) Usefulness for gait problems of all subjects in any phase of rehabilitation: measurement, analysis, training, and/or evaluation.
b) A simple procedure for data acquisition and biofeedback,
c) A low cost and simple hardware,
d) Rich information - length, width and angle of the step, and each duration of gait cycle - which are suitable for numerical assesment /9/ and biofeedback of gait.

The system has also turned out to be very useful and applicable for the improvement in gait during rehabilitation.

Finally, there are three future considerations. The first is to pursue the improved process of pathological gait with this system during a longer term. The second is how to order the temporal-distance factors for more effective improvement. And the third is how to establish the target pattern of gait during rehabilitation.

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