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Biomechanical Analysis of Body Balance

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= Abstract =

Human body sways continuously to maintain balance during upright stance. A computer-aided instrumentation system using a force platform has been developed to investigate the body balance. The Kistler force platform and amplifiers were only used to obtain the precise measurements, and the data acquisition and analysis software operating on an IBM PC with A/D converter was developed. This study presents methods for the display of platform center of pressure data on stability study. This system can be used as a tool in evaluating the man's ability to balance and disorders of the nervous system.

1. INTRODUCTION

Human body balance is stabilized by the constant regulation of the complex neuromuscular system. That is, the maintenance of balance is a dynamic motor skill requiring reception and transmission of signals of proprioceptive sensors in the central nervous system, interacting with visual and vestibular responses. Thus, human body sways continuously to maintain balance while a person is standing upright.

Since Romberg's test in 1853, the analysis of sway of the center of pressure during upright stance has been used widely as a tool in evaluating the man's ability to balance and disorders of the nervous system.

For centuries scientists have attempted to gain an understanding of the dynamics of human standing posture by various methods of measurement. In general, the methods of investigation fall into the following three categories : (1) measurement of the displacement of body segments during standing posture, (2) platform measurements of the movement of what is considered the vertical projection of the center of pressure, and (3) measurements of the muscle activity which controls the inevitable motion of the body, even during attempts to stand motionless. The methods employed were measurements of postural movements, platform measurements, electromyographic studies, or combinations of these[6].

The most widely used equipment for the measurements of sway is a force platform. Force platform has strain gauges or force sensors attached to three or four corners, and the forces measured are combined to produce the position of the center of force in the horizontal plane. When this is done dynamically, the movement of the center of force in the horizontal plane as a function of time can be obtained[2].

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This study concerns with the quantitative measure and biomechanical analysis of body sway using a force platform. A computer-aided instrumentation system has been devised to have an objective, quantitative, and more sensitive measurement of postural stability. The Kistler force platform and amplifiers on Kstler Biomechanics System were only used and the data acquisition and analysis software using an IBM PC was developed. This paper also presents the methods of displaying center of pressure data which may be assessed visually and numerically without the need for further computation.

2. METHODS

Instrumentation

The experimental apparatus used in this study is illustrated in Fig. 1. It consists of three parts : (1) multicomponent measuring platform－Kistler Type 9281B ; (2) electronic amplifying unit(charge amplifiers) － Kistler Type 9861A ; (3) indicating and recording equipment－IBM PC with A/D converter.

The measuring platform(Kistler Type 9281B) consists of four 3-components (Fx, Fy, Fz) piezoelectric force transducers.

Transducers convert the mechanical variable to be measured－force－into an electrical output signal. Piezoelectric transducers yield an electrical charge proportional to the measurand. The measuring platform is connected by a special cable to an electronic amplifying unit, which converts the electrical charges yielded by the force transducers of the platform into proportional voltage.

It is possible to feed the output signals from the charge amplifiers via analog-to-digital converter into a computer and process them digitally.

The role of the connected computer is to sample and convert analog signals from the electronic amplifying unit, store them and finally perform calculations on them in order to obtain the position of center of body pressure.

Kistler Biomechanics System offers a packaged system consisting of a force plate, electronic amplifying unit, plus data acquisition and display software operating on a computer. Because this system is expensive, the Kistler force platform and Kistler electronic amplifying unit on Kistler Biomechanics System are only used to obtain the precise measurements. And the data acquisition and displaying software using an IBM PC with 12 bit A/D converter have been developed to save the money.

Processing of the platform output signal

The measuring platform(Kistler Type 9281B) consists of a frame and top plate, with four 3-component force transducers fitted between them under high prestress(Fig. 2-a, coordinate origin : O).

The following transducer outputs are permanently paralleled and defined and designated

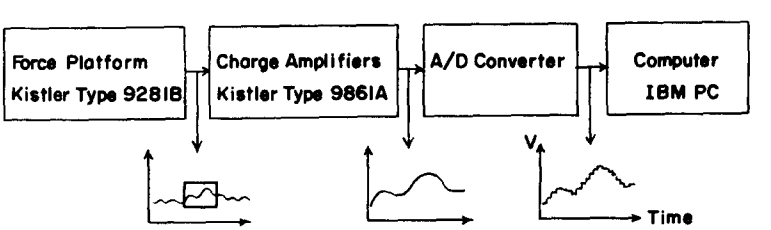

Fig. 1 Experimental Apparatus

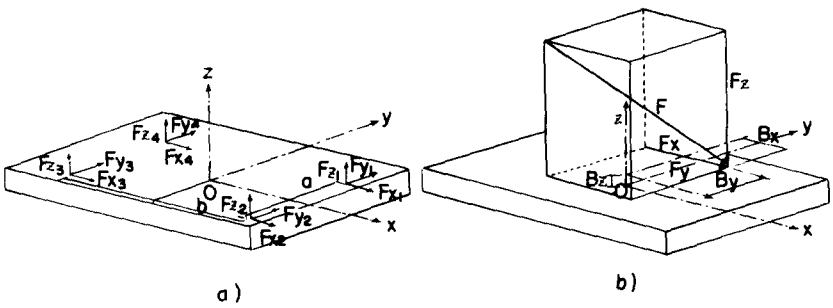

Fig. 2 Force platform and measured variables

as follows as outputs of the measuring platform :

Channel 1 : $Fy_{1+2}=Fy_1+Fy_2$
Channel 2 : $Fy_{3+4}=Fy_3+Fy_4$
Channel 3 : $Fx_{1+4}=Fx_1+Fx_4$
Channel 4 : $Fx_{2+3}=Fx_2+Fx_3$
Channel 5 : Fz_1
Channel 6 : Fz_2
Channel 7 : Fz_3
Channel 8 : Fz_4

where

Fx_i, Fy_i, Fz_i : force components in x, y, z direction on transducer i(i=1..4).

To determine the point of force application (coordinates a_x and a_y) the signals from the transducers must be processed according to the formulae from the mechanical analysis.

Assuming first that only the z-direction forces act on the force plate (in Fig. 2-b, Fx=0, Fy=0, Fz=F), we can obtain the center of pressure using the z-direction force transducers.

Let us now consider the conditions for static equilibrium. That is, for an object to be in equilibrium, both the sum of the forces and the sum of the moment acting on the object must separately be zero.

$$\Sigma Fz=Fz_1+Fz_2+Fz_3+Fz_4-F=0$$
$$\Sigma Mx=F\cdot a_y-a\cdot(Fz_1-Fz_2-Fz_3+Fz_4)=0$$
$$\Sigma My=-F\cdot a_x+b\cdot(Fz_1+Fz_2-Fz_3-Fz_4)=0$$

where

a : distance of transducer axes from y axis
b : distance of transducer axes from x axis

In the general human movement case, however, 3-components forces act on a platform. Since the sum of all the forces and the sum of all the moments must be zero, we have

$$\Sigma\ Fx=Fx_{1+4}+Fx_{2+3}-Fx=0$$
$$\Sigma\ Fy=Fy_{1+2}+Fy_{3+4}-Fy=0$$
$$\Sigma\ Fz=Fz_1+Fz_2+Fz_3+Fz_4-Fz=0$$
$$\Sigma\ Mx=Fz\cdot a_y+F_y\cdot a_z-a\cdot(Fz_1-Fz_2-Fz_3+Fz_4)=0$$
$$\Sigma\ My=-Fz\cdot a_x-Fx\cdot a_z+b\cdot(Fz_1+Fz_2-Fz_3-Fz_4)=0$$

where

a_z : distance of working plane from (x, y) plane

and so

$$Fx=Fx_{1+4}+Fx_{2+3}$$
$$Fy=Fy_{1+2}+Fy_{3+4}$$
$$Fz=Fz_1+Fz_2+Fz_3+Fz_4$$
$$a_x=\frac{(-Fx\cdot a_z+b\cdot(Fz_1+Fz_2-Fz_3-Fz_4))}{Fz}$$
$$a_y=\frac{(-Fy\cdot a_z+a\cdot(Fz_1-Fz_2-Fz_3+Fz_4))}{Fz}$$

Because Fx, Fy, Fz are measured by the measuring system, the coordinates a_x and a_y of the force application point in the working

plane can be obtained. Since Fx, Fy, Fz continuously change with time, a_x and a_y can be calculated to show how the center of pressure moves across the force plate.

In this study, the center of pressure data from the force platform are sampled at 25 Hz. All the digital data accessed are recorded on the RAM disk of IBM PC/XT for the rapid data acquisition. After each test is finished, the data are transferred to floppy diskette. From these data we derive the extent of postural sway.

3. ANALYSIS AND RESULTS

Human posture is characterized by upright standing. Standing erect is one of the most popular and basic working posture. Accordingly, the standing posture has been used widely as a tool in evaluating the man's ability to balance.

The test protocols used in stability studies vary as much as the methods of measurement. Subjects are generally asked to stand with their feet in a standard position, knee locked, and looking straight ahead. The exact position and angle of the feet varies. The majority assess the subject's sway both with the eyes closed and with the eyes open. The time taken for each test has varied from approximately 10 seconds up to 3 minutes. After each test is finished, the amount of sway is calculated from the center of pressure data. The sway is defined as fluctuations of center of body pressure on the force platform.

The following methods can be used to analyze the pattern of body sway :

(1) total sway distance during the test period (accumulated sway distance between the successive instantaneous positions).

(2) the extent of for-backward and lateral postural sway (expressed as total travel in centimeters).

(3) area in the plane of measurement enclosed by the perimeter of the sway path

(4) three-dimensional histogram for center of pressure display (visual representation of the sway distribution function).

(5) ratio of measurements of total sway distance for eyes open to eyes closed (it implies the grade of visual compensation for body balance).

In this research a quantitative measure of the amount of sway is calculated by the computer and displayed as the total length of the locus of sway during test period. Fig.3, Fig

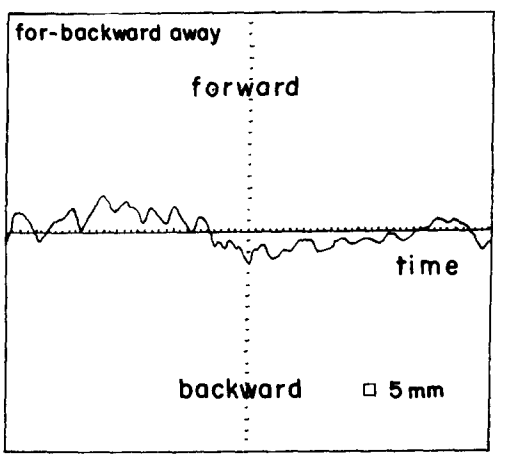

Fig. 3 For-backward sway

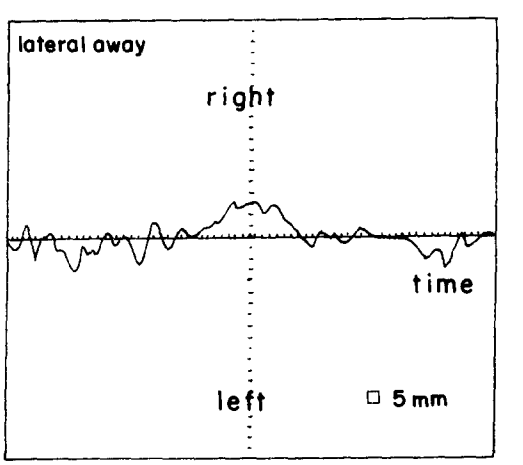

Fig. 4 Lateral sway

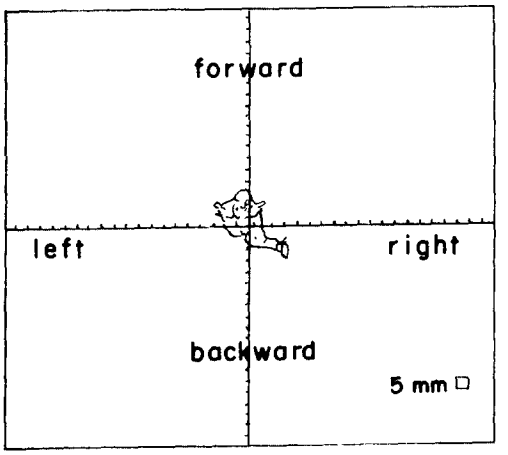

Fig. 5 Postural sway

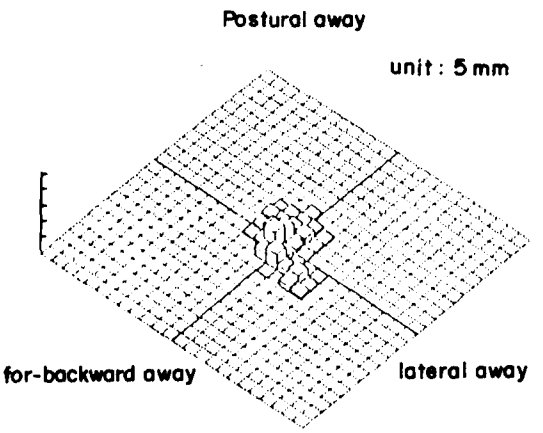

Fig. 6 Three-dimensional sway histogram

4, Fig. 5, Fig. 6 and Table 1 show the pattern of subject's for-backward, lateral, two-dimensional (lateral, for-backward) postural sway, three-dimensional sway histogram and analysis output of sway data for standing upright with eyes open during 30 seconds.

4. CONCLUSION AND DISCUSSION

The measurement system must be required to analyze the human movement precisely and automatically. A computer-aided instrumentation system for the automatic measurement of human movement, especially body sway has been developed. The system consists of a force platform, amplifiers and computer. We used only the Kistler force platform and amplifiers, and developed the data acquisition and analysis software using an IBM PC. This system was used to obtain the continuous records of reaction force and position of center of body pressure.

Table 1 Postural sway distance during 30 sec.

※ mean position (lateral, forward)=(-4.08, -7.48)
※ total sway distance (30 sec.)=312. mm
: mean=10.4 mm/sec
※ lateral sway distance (30 sec.)=197.8 mm
: mean=6.6 mm/sec
※ forward sway distance (30 sec.)=211.9 mm
: mean=7.1 mm/sec

The major advantage of the system consists in the automatic and real-time evaluation of the parameters of postural equilibrium during the performance of the test, and their display in numerical values at the end of the test.

The technique for display of postural information presented herein offers a means for data compression which is visually meaning-ful, yet also quantiitative. The methods of data collection, analysis, and display are suitable for clinical implementation and may be used to study a variety of postural disorders.

It is hoped that the information presented in this study will contribute to a deeper understanding of the dynamics of normal posture and that the standards will provide useful baselines for studying postural abnormalities of a wide variety of disabled patients whose disease processes have affected their ability to function effectively during upright posture.

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