RETRAINING OF STANDING BALANCE USING A PEDOBAROGRAPH

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ABSTRACT

Where upright standing has been partially disrupted by neuro-motor dysfunction, re-education of the skeletomotor control system may be possible by conventional physiotherapy or augmented sensory feedback training. An indication of the nature of the balance problem can be gained from observation of the pressure distribution under the soles of the feet, and may assist in prescribing suitable treatment. A visual map of the instantaneous pressure distribution can be obtained from a pedobarograph; this information may be used in assessment of the patient's function prior to therapy and as augmented sensory feedback in its own right.

Early experience in the use of a pedobarograph with amputees and hemiplegics is described.

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Introduction

Normal standing balance is maintained by integration of the reflexes developed in early life; by this means, each person acquires his own individual posture. Nevertheless, certain common factors are found. For example, when observing the distribution of body weight under the soles of the feet, the centre of foot pressure moves with characteristic defined limits (1, 2, 3). Gross systemic damage to central nervous system, peripheral neuromuscular system or limb may disrupt normal balance and this will be apparent in changes and abnormal weight distribution and movement of the centre of foot pressure. Inability to adapt to the new situation and re-instate a posture within acceptable limits may lead to secondary clinical problems of scoliosis, lower lumbar pain, bone and joint problems or poor gait, if indeed balance in upright standing can be achieved at all. For these reasons, encouraging proper balance and posture is important to long-term welfare.

The process of adaption to a proper posture in changed conditions necessarily requires a re-adjustment of the integration of postural reflexes. The importance of afferent feedback in this integration to maintain posture is already well-established, although the individual contributions made by muscle, joint, vestibular and visual afferentation has yet to be quantified, and is still a subject of study (4, 5, 6).

One of the cornerstones of therapeutic techniques is to provide external feedback which assists in the necessary re-integration of the control system by augmenting and re-inforcing the natural afferent feedback signals. External feedback may be provided either by the physiotherapist or by a technical device; in the latter instance it has become known as 'augmented sensory feedback' although the terms biofeedback and operant conditioning have also been used to describe this technique. The principle of ASF as applied to re-education of the skeletomotor system is briefly as follows. An externally-measured parameter, chosen for its immediate and critical relation to the aspect of skeletomotor control needing correction, is fed back to the subject via visual, auditory or cutaneous senses. This additional sensory inflow augments the natural inflow, and enables the subject to change the measured parameter in the desired manner, thereby improving his skeletomotor performance. For the technique to be successful, several important requirements must be met. The subject must have the physical capability of performing motor actions which will change the feedback parameter, i.e. the efferent pathways and muscles involved in the correction must be at least partially under voluntary control; the feedback must present information not already available to the subject in a modality matched to the sensory channel employed; and the temporal relationship between response and feedback must be close in order to maximise learning.

For patients with sensory dysfunction of the lower limb leading to poor balance, these requirements can potentially be met by feeding back information derived from the pressure distribution under the feet. The Limb Load Monitor developed at the Krusen Centre has already employed this principle to provide useful balance training of hemi-plegic and paretic patients (7, 8). This particular device monitors the total load under each one of the feet separately, and employs a single-tone auditory feedback to indicate lateral postural assymetry.

Experience with the use of the Limb-Load Monitor leads us to believe that more detailed information about the pressure distribution under the feet could be useful in balance training, firstly in assessment of the disturbance to balance prior to therapy, and secondly as augmented sensory feedback in its own right. Consequently we have employed a pedobarograph (PBG) (9, 10). This device was developed by Chodera in 1953 for display of the distribution of pressure in the soles of the foot by proportional distribution of light (11, 12).

The Pedobarograph

The function is based on the conduction of light by total internal reflection in a transparent material such as glass, perspex or polycarbonate and the use of an elastic foil as a means of transfer of pressure to the light conducting surface. The foil is placed between the light conducting surface and the part of the body to be measured. (Figure 1).

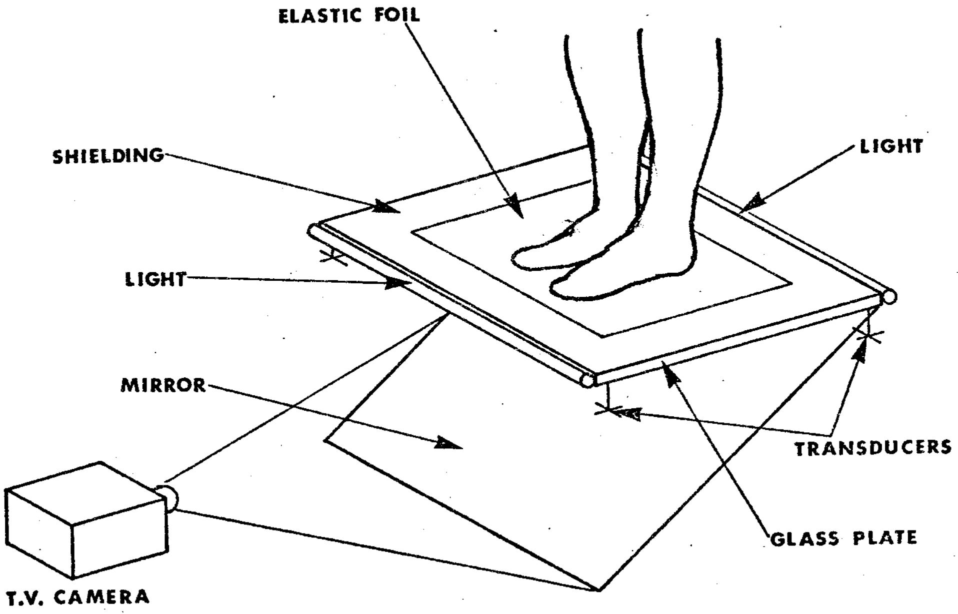

FIGURE 1. The Pedobarograph general lay-out.

The subject is standing on a glass plate with two fluorescent tubes lighting into the polished edges. A plastic foil or foam is inserted between the feet and the glass, the resulting picture is observed in the mirror directly or by a camera.

The system is built in a box to prevent interference from ambient light.

Four transducers may be used underneath the glass plate to record vertical forces for display of the location of the centre of overall pressure - see text.

If no pressure is applied on the elastic foil, the surface of the foil is not in optically active contact with the light conducting material and the viewing field observed from the free (lower) side is dark. Pressure applied onto the foil causes an optically active contact between the foil and the light conducting material whereby the total internal reflexion conditions are changed and the light illuminates the foil. The foil scatters the light back in the area of the pressure and the patterns of the pressure area may be observed and recorded, Figure 2.

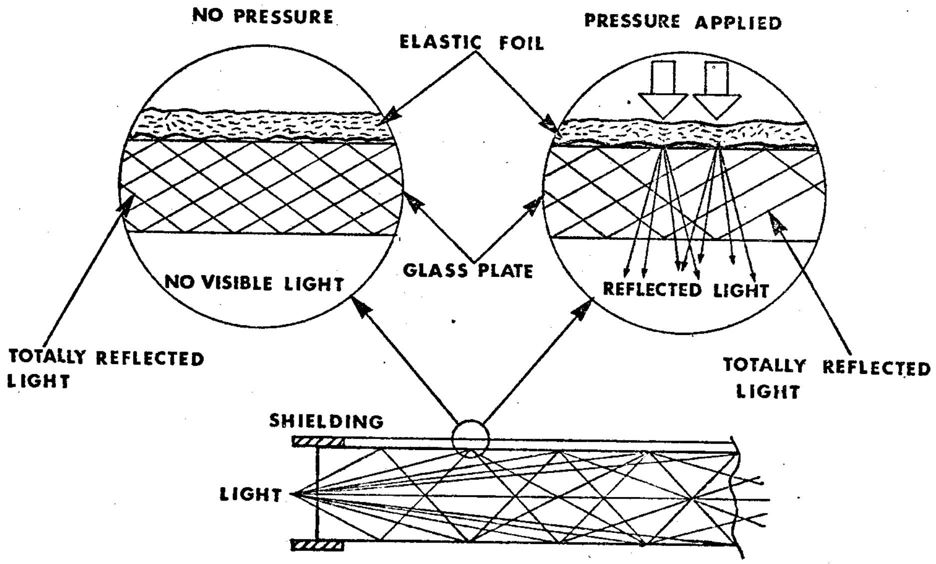

FIGURE 2. The physics of Pedobarogram.

Totally internally reflected light is conducted inside the plate until pressure applied on the plastic foil causes output of the light which is then reflected back through the plate.

The intensity of light emitted is proportional to the pressure applied dependent on the elasticity and microstructure of the foil-to-plate interface.

If the elasticity and surface texture of the foil is such that increasing pressure on the foil brings a proportional number of points into optically active contact with the light conducting material, the pattern observed shows the areas of increased pressure with an increased light intensity. This principle is general and applies to any shape of optical media and any type of foil when the conditions as above are fulfilled.

The resulting picture (Pedobarogram) can be recorded by still or cine photography, or closed circuit television system with videotape and monitor.

Figure 3 shows a Pedobarogram as seen by direct observation in the mirror recorded on black/white film 80 ASA, F4.5, 1/10 sec.

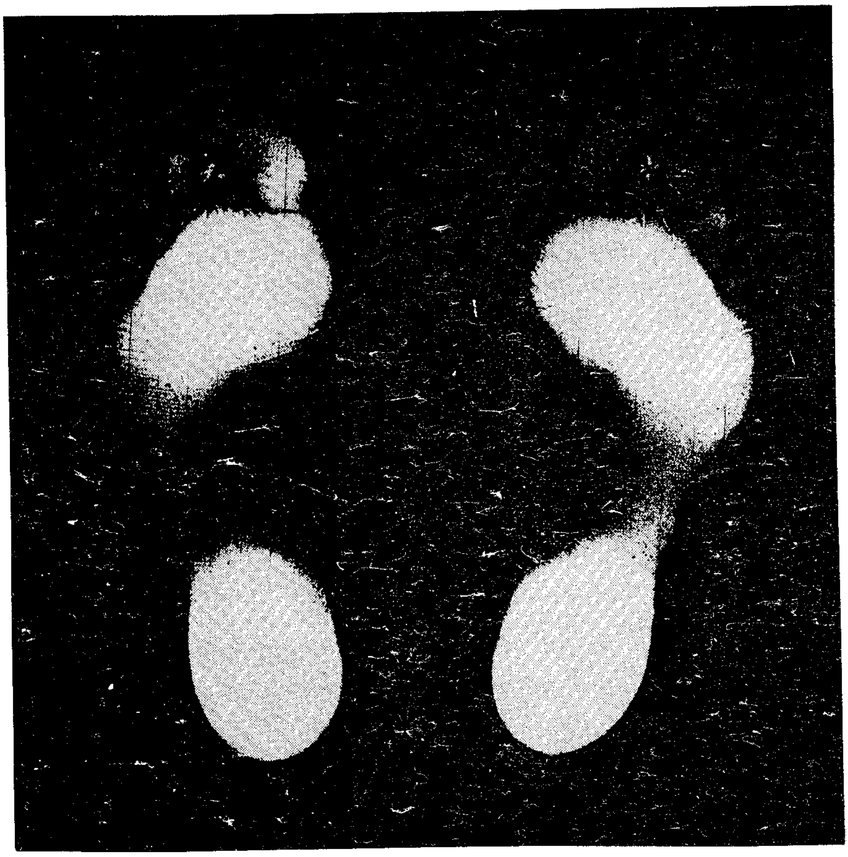

FIGURE 3. Direct Pedobarogram. Female, age 30, neutral standing in stockings. Overall pressure increased on the right, left heel slightly valgus, transversal flat foot M2-3 left, M3-4 right, pressure on the medial part of the big toes, more left. Compare with Fig. 4.

If the black and white TV signal from the camera is processed by a intensity level discriminating circuit, the resulting picture can be converted to a zonal grey scale or colour picture (Fig. 4). Each intensity or colour zone will show the location of a calibrated range of pressure, creating a zonal pressure map of soles. The zonal picture enhances the legibility and evaluation of the pressure pattern.

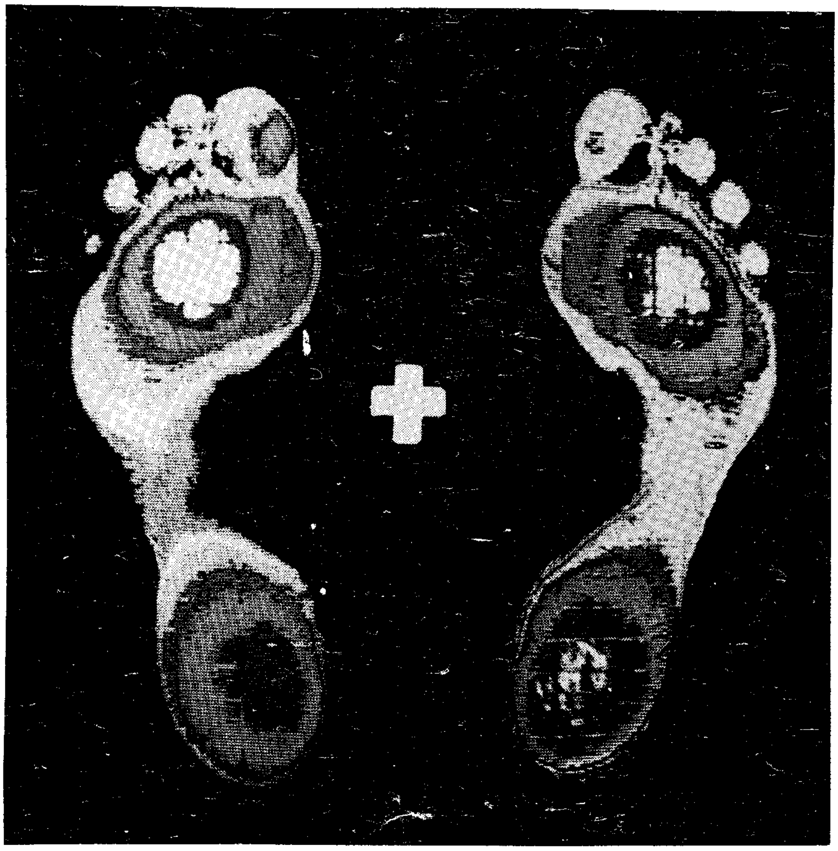

FIGURE 4. Zonal pressure map from the same PBG as Fig. 3. The white cross indicates the position of the centre of pressure.

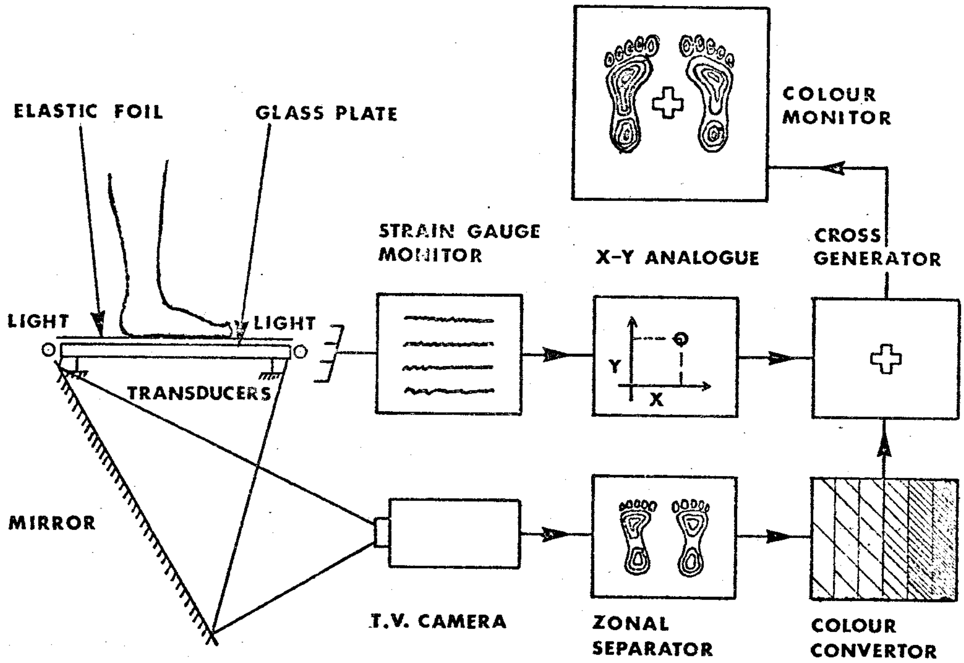

FIGURE 5. Block diagram of the electronics of zonal colour map and centre of pressure display unit.

The addition of four strain-gauge rings under the corners of the glass plate enables the centre of foot pressure to be calculated. Having adjusted the output of the force transducer amplifiers to allow for the weight of the glass plate, analogue circuitry is used to produce a voltage proportional to the displacement of the centre of pressure from the centre of the plate in both medio-lateral and antero-posterior directions. These electronically-generated signals are used to move across on the television monitor, the position of the cross indicating the centre of pressure in relation to the pedobarogram (Fig. 4). The frequency response of the cross display is similar to that of the centre of foot pressure analyser i.e. 10 Hz. This is adequate for our purposes.

Patient Assessment and Training

We used the device both for examination and feedback purposes. From the overall picture we assessed and analysed the patient's situation. This enabled us to take immediate measures for technical corrections of the pressure distribution (such as everting or inverting the forefoot, distributing high pressure in the heel area more evenly, temporarily bracing unstable joints for training purposes where appropriate, etc) and to check on the results of such measures instantly. Both the physiotherapist and the patient learned from the television screen about the details and the problems found. The load monitoring soles, when applied, were adjusted to efficient levels for subsequent training. Alternatively we used the device itself for visually controlled feedback training in the following way.

First we noted the current position of the cross in the PBG picture. Typically it was found on the unaffected side of the footprints. Then the extent of its movements during instructed effort to improve the balance of standing was tested. Undesirable areas of movement were noted, and a piece of transparent coloured film was cut to shape and size according to patient's abilities and placed on the screen. The patient tried to stay upright and keep the cross within the marked target area. Generally patients took the challenge of the task as playing a kind of TV game. This motivation was helpful for concentration and endurance. The length of a daily session was set according to the patient's ability.

In a similar way, we were able to help with immediate assessment of the required technical corrections for lower-limb amputees. Resulting changes in vertical alignment or control of, say, foot-shoe functions helped in the subsequent training of shift of body weight towards the prosthetic side. Most patients were unaware of the way in which they stood. Playing the game with the cross helped the patients after amputation to overcome their initial difficulties due to fears of lack of balance.

Results were encouraging in the preliminary study cases. Improvements were noticeable within a week of training and physiotherapists appreciated the advantage of instantaneous assessment facilities; especially with the variability of problems in hemiplegics. No statistical analysis of the efficiency of the technique is available as yet as this is a preliminary report.

Conclusion

The use of centre of foot pressure (C.F.P.) is already established in assessment of upright balance (13, 14). Our contribution is in the combination of Pedobarographic and C.F.P. measurements. The advantage is the instantaneous complementary information which can be gained about the detailed pattern of the pressure distribution and the overall balance problem. The device enables immediate assessment and re-assessment of corrective measures and involves the patient and physiotherapist in the visual monitoring of progress. By aiding the side problem of technical assistance to balance in a fast and efficient way, and combining instant information on the state of balance with motivation and augmented sensory feedback training, we hope to increase the efficiency of the re-education process. A simultaneous reduction in the time needed for training and the labour involvement of the physiotherapist may be achieved. Such an approach should fit well into the trend of development of therapeutic medicine.

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