NUMERICAL ASSESSMENT OF STANDING BALANCE IN HEMIPARETIC PATIENTS

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ABSTRACT

Force plate techniques have long been in use to record the natural swaying motion of a subject nominally at rest. The movement of the Centre of Foot Pressure defined on the support plane ('Stabilogram') and the asymmetry of loading between the two feet are two common presentations of force plate recordings. In this paper such records are processed to provide a numerical measure relevant to the degree of abnormality in hemiparetic patients. It is intended to use this measure to evaluate both the rate of natural recovery and the efficacy of therapeutic treatment post-cerebrovascular accident (CVA).

Since the CVA patient may not be able to undergo assessment under standardised conditions (e.g. fixed foot placement, arms hanging at the side, eyes closed or focussed on a target), the influence of these special factors on the performance during assessment is given consideration. Non-CVA subjects have been tested (in order to acquire a measure of 'normal' performance) under similar conditions to those found clinically necessary for assessing CVA patients.

The assessmments described have been developed as part of an evaluation of the use of a Pedobarograph to retrain standing balance, described previously at this conference (1).

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Introduction

It has been recognised for over a century that the maintenance of upright posture in man is a constant, continuous process of adjustment. This is commonly termed 'postural sway'. Damage to the central nervous system such as a cerebro-vascular accident (CVA or 'stroke'), often results initially in an inability to control postural sway and to achieve standing balance.

In a previous communication to this conference, Chodera and Lord (1) discussed the possibility of using a pedobarograph to retrain standing balance in CVA patients. The pedobarograph gives a visual display of pressure under the soles of the feet, and is used as a biofeedback device during training sessions for hemiparetic patients as described by Smith, Lord, and Kinnear in these proceedings (2). A controlled trial of this pedobarograph therapy is in progress at Roehampton, and the numerical assessments of standing balance presented here have been developed specifically for use in this trial.

In particular, an assessment of sway was sought which would be sensitive to the progress of recent CVA patients from the stage of barely being able to maintain upright posture through to a near-complete recovery. This specific application imposes restrictions both on the manner in which tests can be performed due to the patients' limited abilities, and on the meaningful analysis of the results. In this paper we describe specific methods of assessment of standing balance developed in the light of experience with hemiparetic patients. Additionally, the results of control assessments on normal subjects are presented for comparison.

Assessment of Balance

Normal postural balance is achieved by the integrated control of a number of body segments in both the saggital and mediolateral planes. Of particular importance in this process is the control of the ankle joint, and in the simplest model of saggital postural sway the body is considered to be a rigid member from the ankle upwards which sways because of the continuous adjustment of the angle of flexion at the ankle (3). This model has gained widespread support. A lateral component of sway is also evident, although usually reported to be of lesser magnitude (4); this sway is thought to be controlled at the pelvic level.

If it is assumed that the body sways as a rigid member, then the sway movements can be characterised by the motion of the centre of gravity (C of G) of the body in a horizontal plane which is anatomically located at hip height. The movement of the centre of foot pressure (CFP) in a horizontal plane at floor level may be used similarly. At very low frequences these two displacements correspond (i.e. at less than about 0.1 Hz), but at higher frequencies the movements of the CFP are considerably amplified on those of the C of G because of additional components of force related to accelerations of the body (5). Both movement or accelerations of the C of G as recorded by displacement or acceleration transducers attached to the hips, and movement of the CFP, obtained from a force platform on which the patient stands, are used to monitor sway. For our purpose, the CFP movements were selected as most appropriate, both because this gives a combined measure of displacement and accelerations related to sway, and because this measurement does not require attachment of transducers to the subject, thus improving practicality.

Records of the movement of the CFP over a period of standing produce a two-dimensional plot referred to as a 'stabilogram'. An example of a stabilogram for a normal subject in quiet standing for 60s is given in Figure 1, where it can be seen that the movement is contained in a small envelope of sway approximately centred between the feet and slightly forward of the ankles. Numerical measures which may be taken to describe this stabilogram include the anterio-posterior and mediolateral range of the envelope, the envelope area, the mean position of the envelope with respect to foot positioning, and the total distance travelled by the CFP. The mean speed of movement of the CFP can also be computed from the distance in a fixed time; this is a comparable measure to that employed by Fernie and Holliday (6) for movement of the C of G. A frequency spectrum can also be computed from the time history of the trace. For a hemiparetic patient, the stabilogram may look similar to that of Figure 2. It can be seen that the mean position of the envelope may be displaced to one side, reflecting the patient's preference for the non-involved side of the body; the sway envelope is larger and less well defined, showing large excursions during brief losses of balance which probably required a conscious corrective action; and the mediolateral motions may be exaggerated.

For normal subjects, stabilograms can usually be recorded under closely controlled conditions - feet fixed in position, arms hanging at the sides, eyes focussed on a target or closed to consider the effect of visual stabilisation, as in the classic Romberg test. When assessing the recent CVA patient, it may not be possible to impose these conditions. Firstly, at the point of entry into standing balance therapy, the patient may not be able to maintain balance at all without either the support of a handrail or occasional corrective actions from a physiotherapist to avoid loss of balance, and it may not be possible for the patient to retain balance with the eyes closed. Occasionally foot positioning is determined by reflex patterns of muscular actions. The attention span of the patient may be low, and balance may be lost occasionally due to distraction.

Consideration of the above constraints led to the following decisions:-

(1) The lateral deviation of the mean CFP position is a predominant characteristic of hemiparetics, and hence required to be measured accurately. Since it is not always possible to standardise foot positioning, an additional laterality test is conducted to obtain this asymmetry. The patient is required to stand with one foot on the force platform, and the other on adjacent ground for a fixed period; the percentage of body weight borne under each foot is monitored.

(2) No tests would be conducted with the eyes closed.

(3) If required, the patient would be allowed minimal support from a handrail.

(4) Occasional brief losses of balance which required corrective action from the therapist would be tolerated, provided that the feet remained in position.

(5) Some attempt would be made to judge the patient's ability to compensate for small disturbances to balance. The manoeuvre of raising the arms to shoulder level has been used previously to provide such a disturbance (7); because of the nature of the patient's disabilities, it was decided to require the patient to raise only the non-involved arm, if at all possible.

A control series of assessments was instigated to monitor the effect of handrail support and arm-raising manoeuvres on the stabilograms of normal subjects tested under similar conditions to those developed for hemiparetics.

Procedure for Patient Assessment

Two tests are conducted for each patient in a laboratory. The patient is wheelchaired into position adjacent to a force platform which has adjustable handrails fitted each side for his safety. The patient is allowed to sit quietly for approximately five minutes to acclimatise to the laboratory environment and during this period the nature of the tests is explained to him. The laboratory is closed off for the duration of the tests in order to minimise distractions.

For the first test the patient is asked to stand on marked foot positions (20 cm centres) on the force platform, arms by his sides, and to look straight ahead at a target cross placed 4 m directly ahead of him at approximately eye level. He is asked to stand as still as possible and not to speak. A therapist stands in attendance but out of his field of vision. The therapist indicates when the patient is ready to commence the test whereupon approximately 10 secs. is allowed for him to "settle down", then movement of the CFP is recorded as described below for one minute duration. On completion the patient sits down and relaxes for a period of five minutes before proceeding with the second test. This is as the first test but in addition the patient is instructed to raise his non-involved arm forward to shoulder height and to hold this position for 15 secs. in mid period.

This procedure is repeated on three consecutive days at approximately the same time of day both before commencement and again on completion of two weeks balance training on the pedobarograph.

Procedure for Normal Controls

A control group of "normals", age range 18-70 years, was also studied and stabilograms obtained for the following tests:-

(1) Standing barefoot on marked foot positions (20 cm centres) on the force platform with both arms by sides, looking straight ahead at a target cross placed 4 metres directly ahead of them for one minute.

(2) As test 1 but with the addition of raising the right arm forward to shoulder height and holding this position for 15 secs. in mid period.

(3) As test 2 but this time raising the left arm in similar fashion.

(4) As test 1 but with the dominant hand lightly holding the handrail throughout the one minute period.

(5) Standing with arms by sides and feet positioned as for test 1 on force platform but with the left knee flexed such that the majority of weight is under the right foot.

(6) As test 5 but with the right knee flexed such that the majority of weight is under the left foot.

Tests 1, 2, and 3 are directly comparable with those conducted with the stroke patients whilst test 4 compares with patients who cannot stand without assistance from the handrails. Tests 5 and 6 were an attempt to simulate the laterally asymmetric standing of stroke patients.

Data Acquisition and Analysis

Records of the saggital and lateral movement of the CFP are recorded for approximately one minute while the patient or subject adopts a posture as specified earlier. The CFP movements are generated by the outputs of a force platform on which the patient stands with his feet centred as far as possible on footprint outlines (see Figure 1). The platform is similar to the Kistler commercial type in design and specification; hardwired analogue circuitry generates the two displacement outputs from the four vertical forces under the corners of the plate.

When the patient is ready for the test to begin, the CFP movement is logged via an analogue to digital converter ('AR11' with 10 bit accuracy) into a PDP11-40 computer, with 2 channels of data each sampled at 50 samples/s for 61.44s (3072 samples per channel). A direct full-scale plot of the movement is made simultaneously on an X-Y pen recorder to provide a monitor of the trial, and this is compared with a computer-graphics display of the digital record immediately post-trial for verification of the recording.

Off-line analysis is performed subsequently to obtain two numerical measures. The first analysis programme computes the total distance travelled by the CFP during the fixed-duration trial, and enables a mean speed to be calculated.

The second analysis programme is designed to give a measure of the area of the sway envelope. In other reports relating to sway and stabilograms, the total enclosed area is used as the measure. (8). However for stroke patients, who often lose balance momentarily during a one-minute trial and consequently produce a sway envelope with a large projecting loop corresponding to the voluntary correction, the total area of the stabilogram is not felt to be a meaningful measure of postural sway. An alternative measure of area which seeks to quantify the area of stabilogram representing sway during the major part of successful balance has been adopted. Essentially, an arbitrary 10% (or approximately 6 seconds) of the original record where the density of line is low is excluded; this device allows parts of the enclosed area when the CFP makes excursions into areas which are not representative of the normal balance to be disregarded. To do this, the X-Y stabilographic plot is divided into a matrix of small rectangles, and the time spent in each rectangle (as estimated by the number of samples falling within the rectangle) is computed. Rectangles with no samples or a small number of samples falling within them are counted as zero density, and the level of samples which is considered to give a positive density is adjusted until 90% of the samples fall in positive rectangles. A plot of these denser areas is then made, and the total dense area computed (Figure 3).

Results-Control Subjects

Visual examination of the stabilograms obtained for the control group in normal standing for 60s (test 1), showed that movement in the A-P direction fell within a range of 12-50 mm (mean 23.42 mm) whilst in the M-L direction it was within the range 5.5-19 mm (mean 10.16 mm). No consistent pattern was observed for any age group, dominance, or sex. Figure 4 shows an example set of stabilograms conducted with a normal subject.

For the six standard tests performed on normal subjects, a summary of the dense area analysis is given in Figure 5. It was found that individuals varied considerably in the absolute areas of these stabilograms, although the variation with test number was fairly consistent. For this reason, the results in Figure 5 have been normalised to show the area as a percentage of the total area summated over the six test runs for each subject. In absolute terms, the average total area was 1185 mmxmm (sample standard deviation 570 mmxmm). This large deviation was due at least in part to the range of ages of the twelve subjects (18 to 70 years); it is thought that stabilograms increase in area in the young and old.

From Figure 5, it can be seen that the manoeuvre of raising the left or right arm in the middle of the minute test period caused an increase in area of approximately 50% (tests 2 and 3). The effect of resting one hand lightly on a handrail was dramatic, reducing the area to less than 50% of the unaided value (test 4). Since the subjects were instructed not to lean on the rail, and did not take any appreciable load through their arms, it must be concluded that this reduction is achieved by a process of sensory feedback. Tests 5 and 6 showed on average similar results to 2 and 3; that is, an increase of approximately 50% is incurred by transference of weight predominantly onto one foot. However, a large variance was noted in these tests of lateral asymmetry, for which two explanations are offered. In the first place, each subject interpreted the instruction for the requisite posture differently, and no check was made on the actual percentage of asymmetry. Secondly, individuals frequently produced large variations between asymmetrical posture favouring the right or left leg, which may be due to a consistent 'leggedness' or simply a random variation. This difference was as marked as a percentage area ratio of 16:42 in one case, and 30:15 in another.

Path length analysis showed similar trends to area analysis. However, a problem was encountered due to the signal/noise ratio of the two C.F.P. signals. Although the noise levels were not excessive for standard laboratory equipment, high frequency noise at even very low amplitudes gives an appreciable additional pseudo-length to each path computed. The relatively high band-width of the C.F.P. movements, which have signal content up to at least 10 Hz, restricts the effectiveness of low-pass filtering. For these experiments, the path lengths were of the order of 650 mm for test 1, although the contribution of noise could be as high as 200 mm (as estimated from static band tests).

Results - CVA Patients

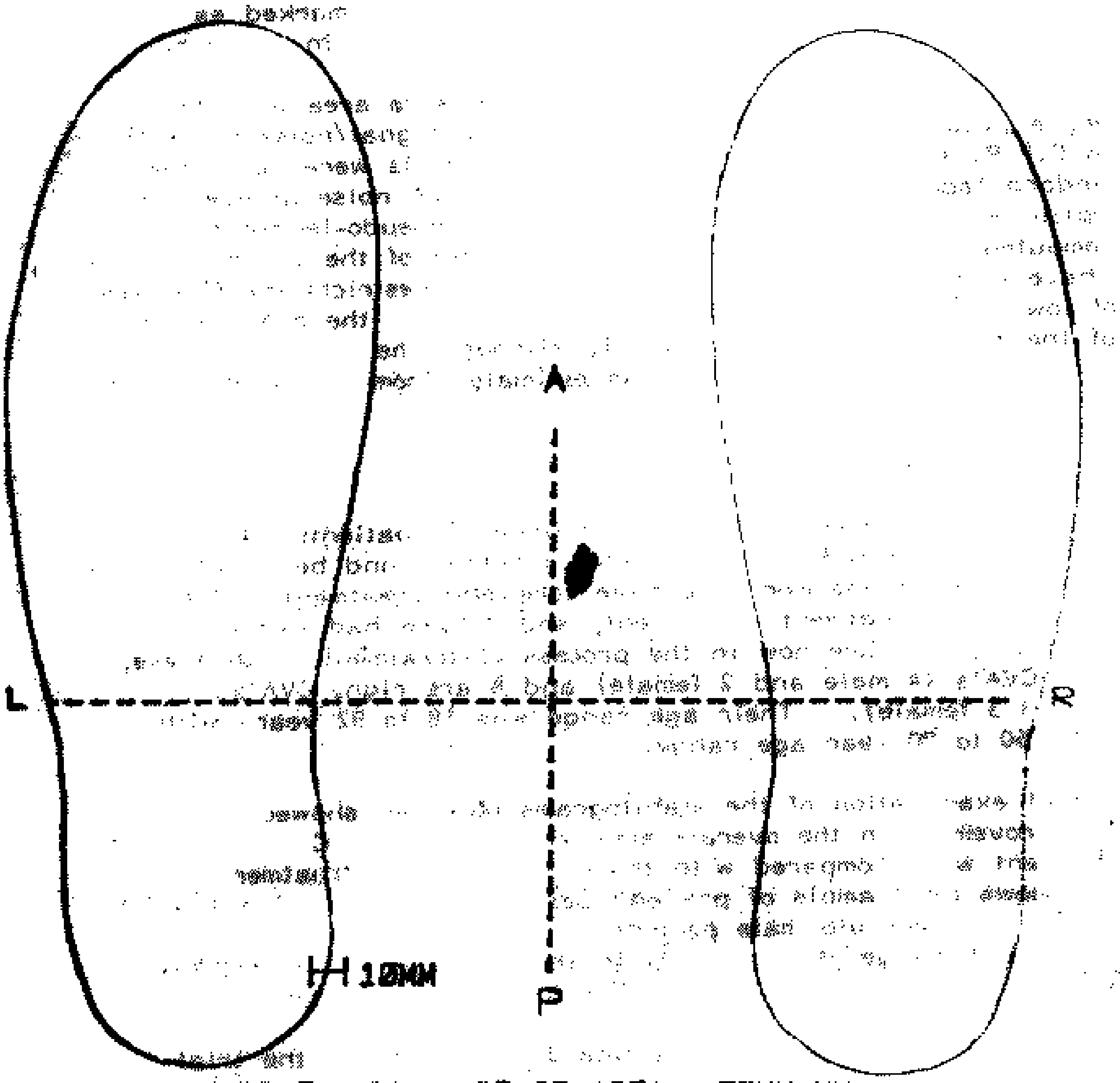
At the time of presentation of this paper 14 patients have been assessed of which 9 have completed treatment and been reassessed after an interval of one month, 2 have completed treatment and have had pre and post treatment assessment, and 3 have had initial assessment only and are now in the process of treatment. Of these, 6 are left CVA's (4 male and 2 female) and 8 are right CVA's (5 male and 3 female). Their age range was 18 to 92 years with 64% in the 60 to 80 year age range.

Visual examination of the stabilograms obtained showed a marked improvement in the overall area of the trace of C.F.P. variation post treatment when compared with those obtained pre treatment. Figure 6 shows an example of pre and post treatment stabilograms for a right CVA, 57 year old male patient. The reduction in overall area and in the range of excursions in the M-L and A-P directions is clearly apparent.

Six patients were able to stand unaided on entering the trial and visual examination showed their gross mean variation of C.F.P. to be 44.7 mm and 36.8 mm in the A-P and M-L planes respectively. On completion of treatment these figures were 33.9 mm in the A-P plane and 22 mm in the M-L plane. All but one of these patients showed a significant reduction in variation of C.F.P.

Conclusions

Stabilograms recorded from recent CVA patients may provide a basis for numerical assessment of postural sway, of sufficient sensitivity to follow the progress of the patient through a course of therapy. Particular problems are encountered in analysis because of the nature of the balance irregularities of recent CVAs. A method of analysis based on the stabilogram area has been suggested, and the results of this evaluation performed on normal subjects under test conditions appropriate for CVA patients are presented. These form a basis for comparison of the performance of the patients.



PERCENTAGE TIME = 93   DENSE AREA = 77MM*MM

Figure 1. Stabilogram for normal subject, aged 25 years. The footprints shown are marked on the force-plate, **and** the subject centres his **feet as** far **as** possible **within these outlines.**

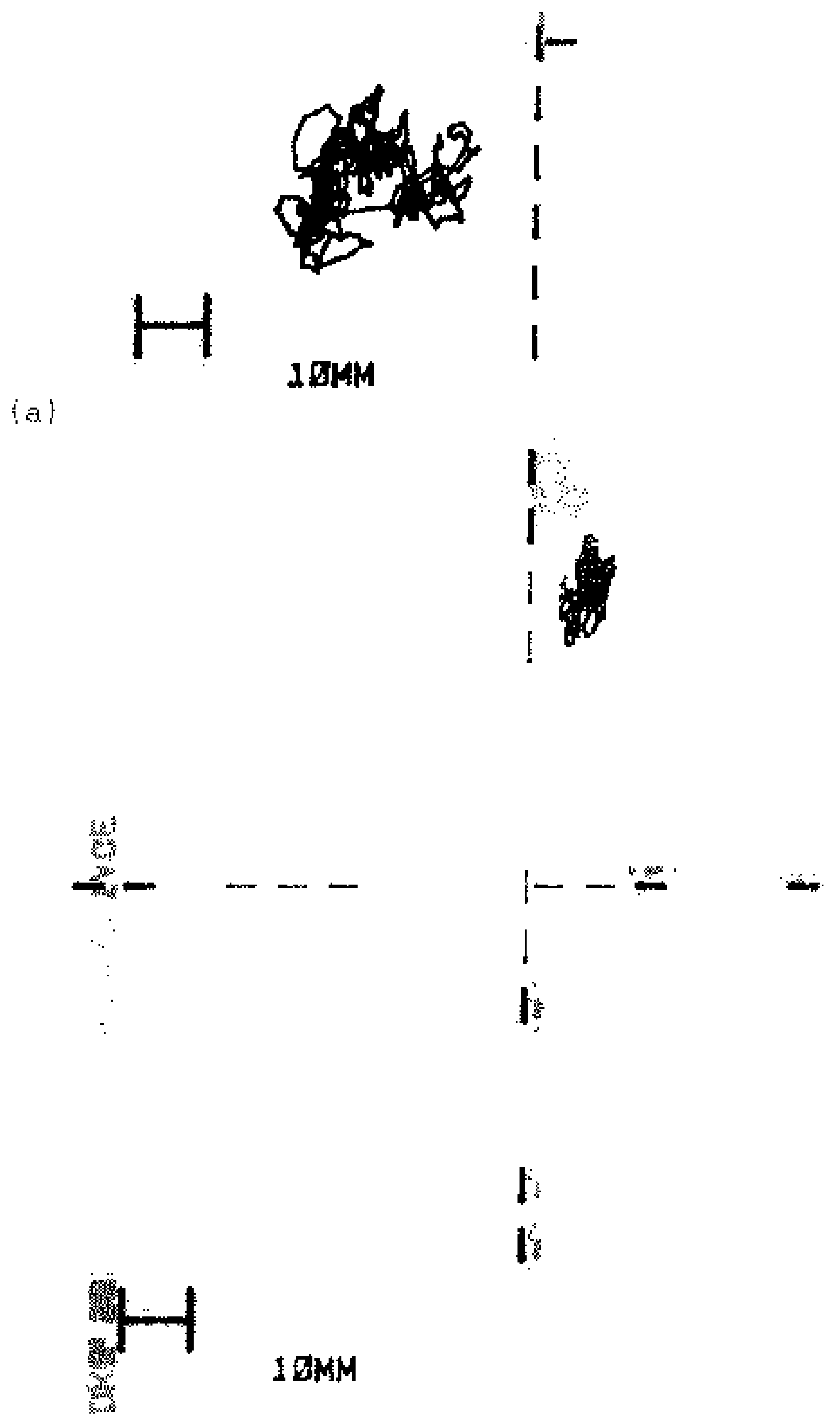
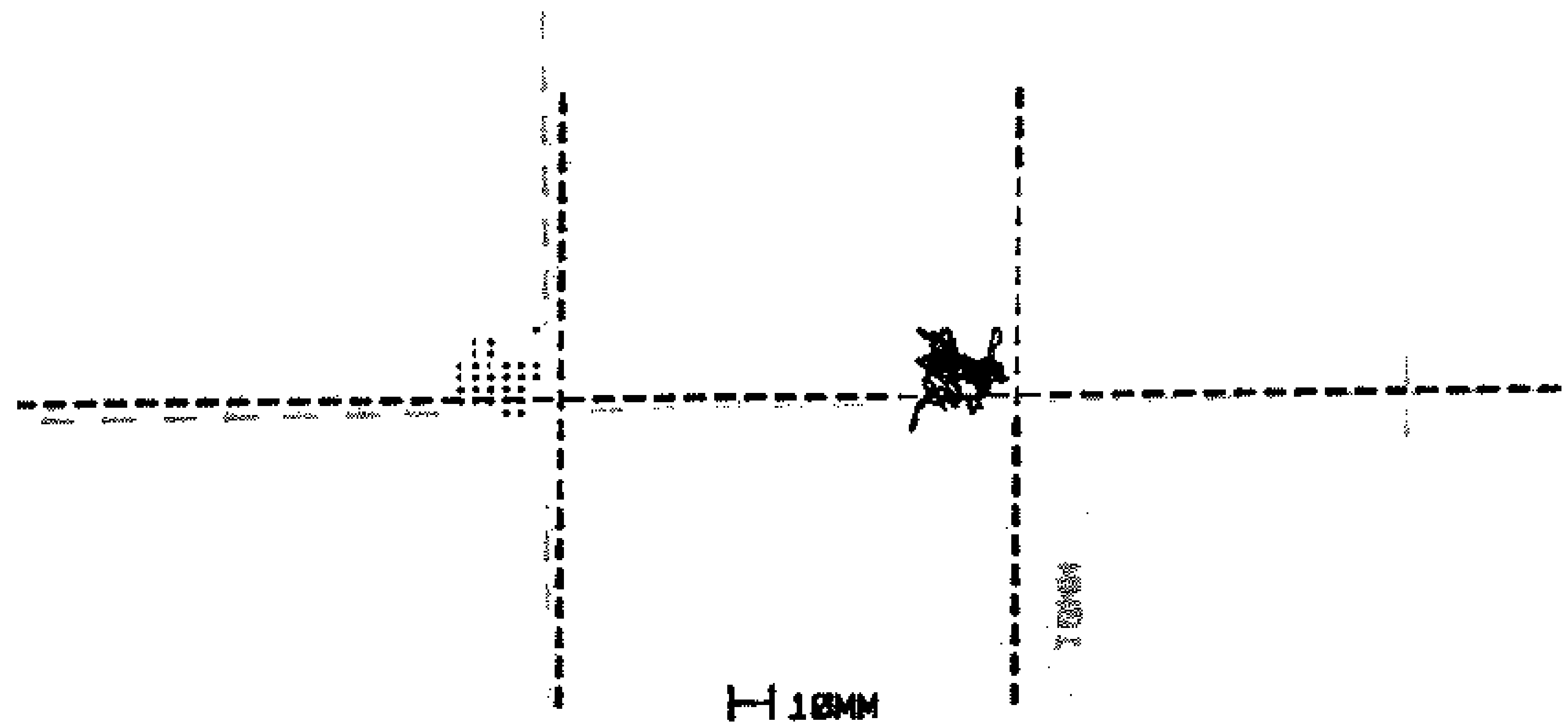


Figure 2. (a) Shows a stabilogram for a left CVA patient, 68 years of age in unsupported stance for 61s.
(b) Shows a typical stabilogram for a normal subject in comparison. Axes with respect to foot position as in Figure



DKØ. SØ1SØ1 PERCENTAGE TIME = 9Ø DENSE AREA =821MM*MM

Figure 3. Example of analysis. Trace on the right represents raw data as in Figure 1; on the left, the dots mark the area of high density.

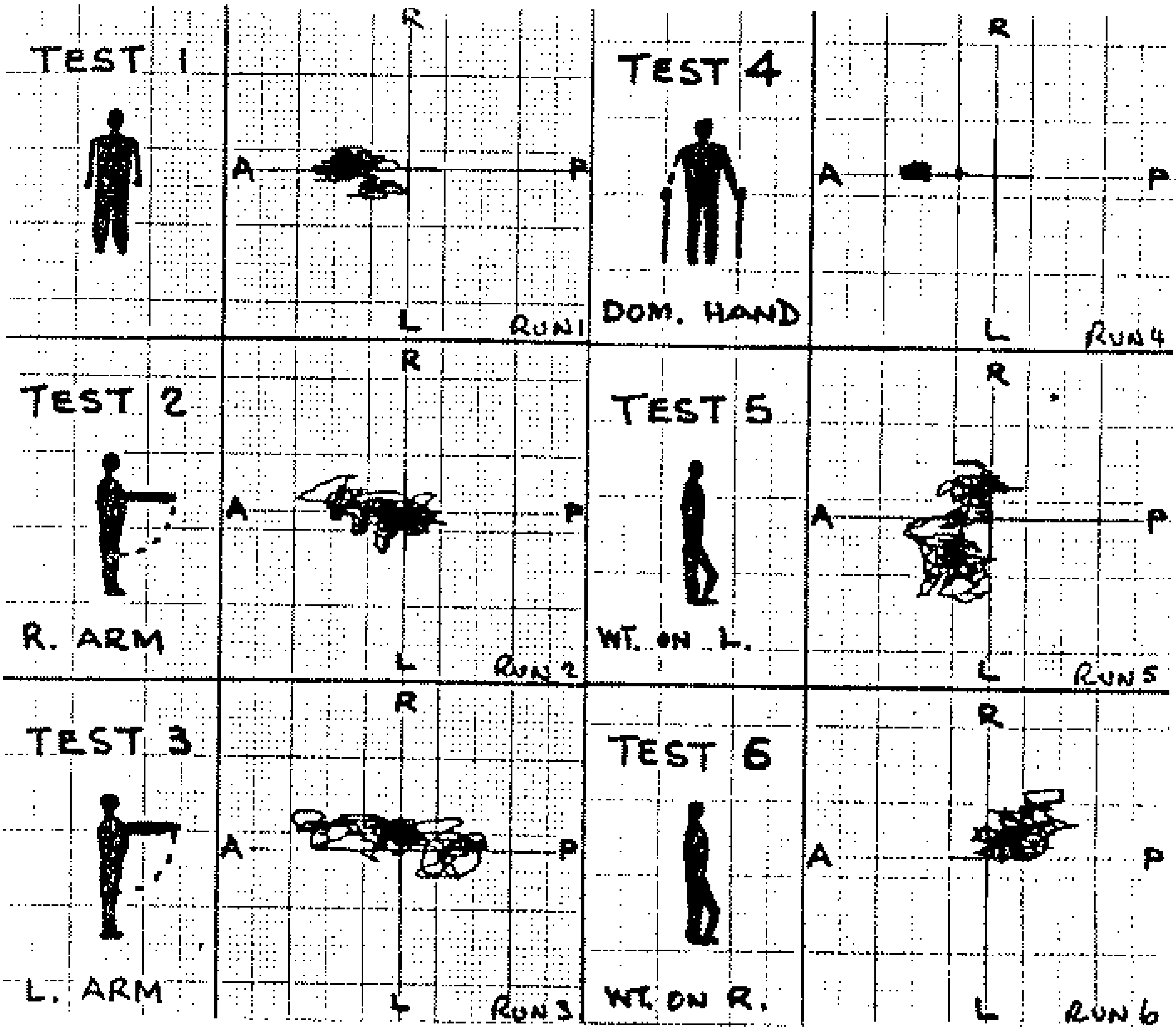


Figure 4 shows an example of stabilograms obtained for the six standard tests performed with a 25 year old right dominance normal male subject.

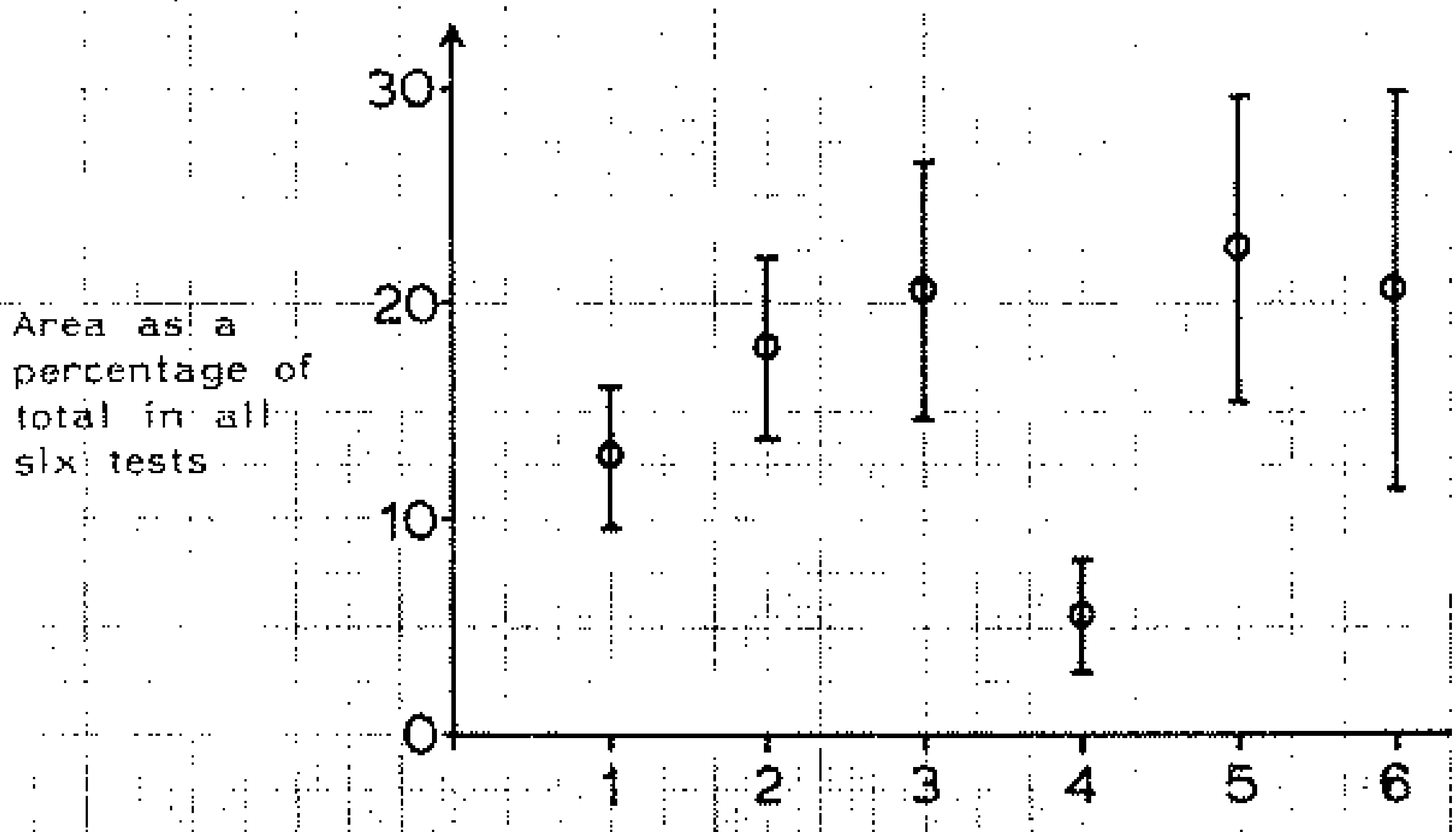


Figure 5. Results of area analysis of stabilograms for 12 normal subjects performing standard tests number 1 to 6 as described in the text and shown in Figure 4. Mean and sample standard deviation are indicated.

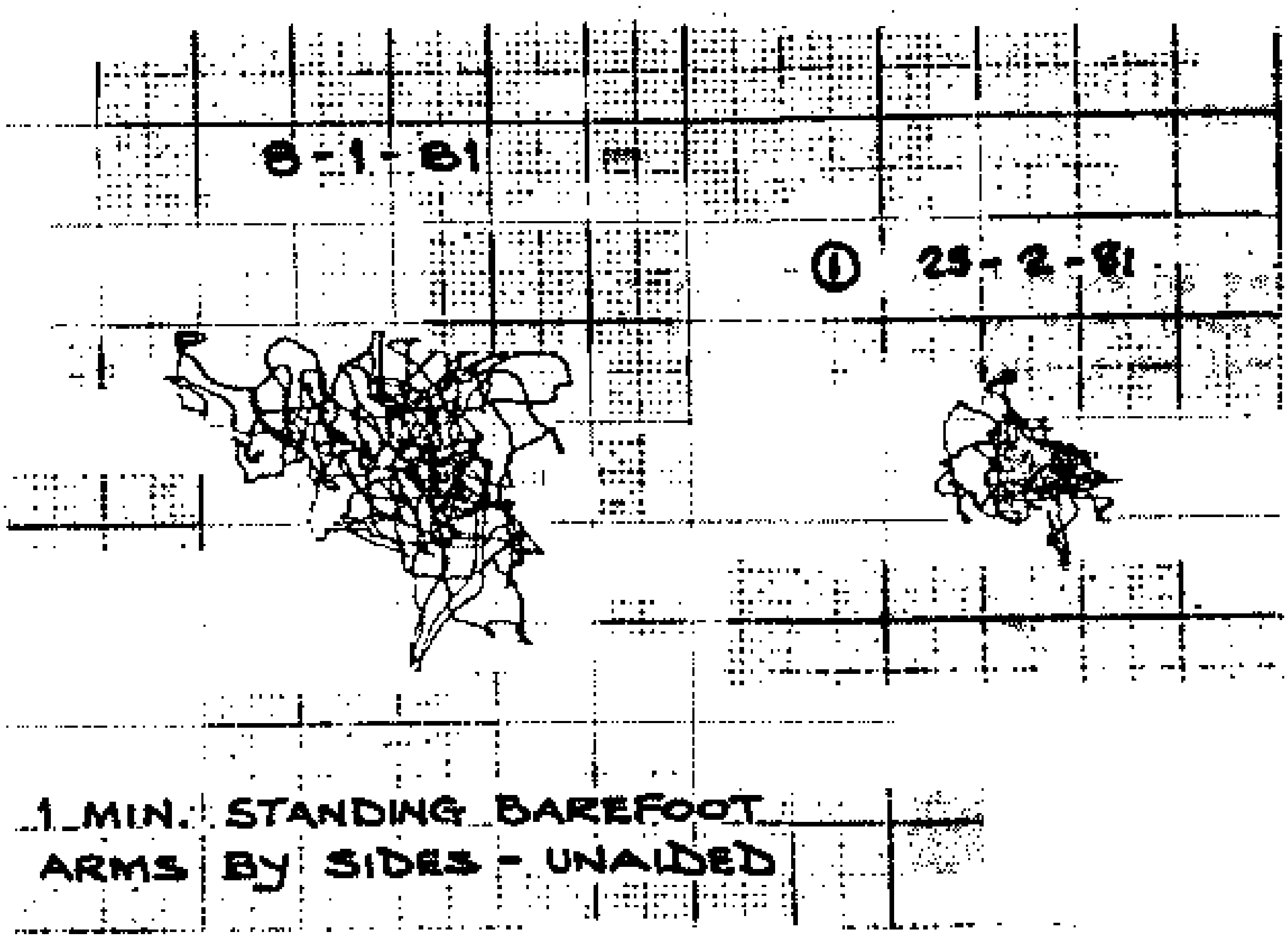


Figure 6. Shows an example of stabilograms for a 57 year old right CVA male patient, (a) before (4 weeks post CVA) and (b) after 2 weeks treatment on the pedobarograph.

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