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Test-retest reliability of the Chattecx Balance System in the patient with hemiplegia

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Abstract—The purpose of this study was to determine the test-retest reliability of the Chattecx Balance System in the patient with hemiplegia. Twenty patients (14 male, 6 female; 14 right hemiplegia, 6 left; mean age 69.5, range 32–86 years) undergoing physical therapy, were tested on the Chattecx Balance System at the same time on 3 consecutive days. Subjects were tested on a static platform, and also using linear translation (anterior-posterior movements), and rotational angular motion about a mediolateral axis. Day 1 was used to allow the patient to become familiar with the testing equipment and the protocol. Data collected from days 2 and 3 were compared statistically using Intraclass Correlation Coefficient (ICC) formula 3,1. Comparison of the center of pressure in the mediolateral direction (COBX), the center of pressure in the anteroposterior direction (COBY), and dispersion index were analyzed for each of the three protocols. ICCs ranged from 0.58 to 0.92 for the static platform, 0.46 to 0.83 for the linear translations, and 0.62 to 0.89 for the angular rotations. Results using this testing protocol showed COBX to be highly reliable for the static and moderately reliable for linear and angular testing protocols. COBY was not reliable for any test condition. Dispersion was moderately reliable only for the static and angular testing protocols. From a clinical standpoint, measures that were found to be highly or moderately reliable may be useful for demonstrating the progress of patients with hemiplegia in their rehabilitation programs.

Key words: *balance, hemiplegic, reliability.*

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INTRODUCTION

Balance can be described as the ability to maintain the center of gravity of the body over the base of support (1–3). It is an essential part of movement, skill, and independence, and it can be affected by drugs/medications, muscle weakness, trauma, and central nervous system (CNS) disorders (2).

Patients with hemiplegia commonly display balance deficits that limit their functional ability. Balance and weight-bearing patterns in the hemiplegic have been previously studied (4–9) by methods including digital scales, foot-ground pressure systems, and electromyography.

Common balance-related deviations which have been identified in these patients include greater sway trajectories and velocities during quiet standing and longer response times to regain balance following externally applied forces (4,9–11). Significant alterations in weight-bearing patterns have also been found (5–7,12). These studies have shown a decrease in weightbearing on the affected side and a decreased ability to shift weight onto the affected side (4,6,8). These deficits may be influenced by mechanical, cognitive, physiological, and sensorimotor factors (11,12). This decrease in weightbearing leads to abnor-

mal lateral stance steadiness, which is a major cause of falls toward the hemiparetic side in these patients (7). Weightbearing through the impaired side is believed to reduce this sensory deficit and is commonly used as a therapeutic exercise (7–9).

The evaluation and treatment of balance disorders is an integral component of a comprehensive post-cerebrovascular accident (CVA) rehabilitation program. This makes it necessary to have a consistent objective means of measuring balance capabilities, in order to document patient progression and to assess readiness to go on to the next level of training. There are three systems that give input to the CNS regarding status and maintenance of balance: vestibular, visual, and somatosensory (2). The vestibular system provides information about the body's relationship to the earth's gravity. It functions to compare and correlate the other two components in the event of discrepancies. The visual system provides information about the body's relationship to objects around it and the movement of those objects. The somatosensory system is essentially a two-part system made up of proprioception, which provides information on self-to-self relationships through joint position receptors and muscle spindles, and exteroception which provides information about the supporting surface (2). In order to possess normal postural control, it is necessary to have functioning sensors and afferent pathways, to be able to integrate this sensorimotor information in the central nervous system, to achieve appropriate distribution of impulses to the spinal motor centers, and there must be adequate neuromuscular output, with an intact skeleton and muscles, to carry out the required movements (1).

In the clinical setting, balance assessments usually consist of gross, qualitative evaluations of a patient's balance ability, giving the clinician a subjective impression as a basis for estimating dysfunction. Methods of balance testing used in the clinic include functional tests (tiltboard, autotilt test, reaching test, one-footed balance, postural sway) and standardized tests (Sensory Integration Praxis Test, Fugl-Meyer Sensorimotor Assessment, and the Standardized Clinical Balance Based on Time). However, there is a clear need for more objective, standardized methods of measuring the patient's ability to balance.

The Chattecx Balance System (CBS: Chattecx Corp., Hixon, TN) as shown in (**Figure 1**) is a computerized system able to give objective information about weight-bearing patterns and balance, both statically and dynamically.

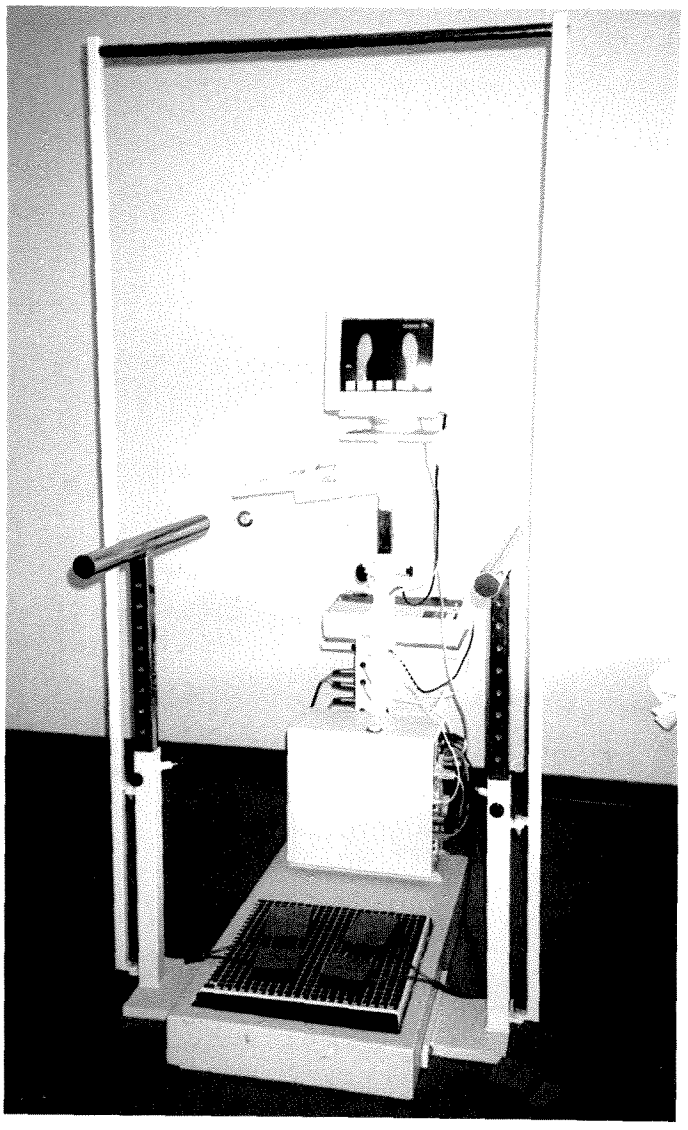

Figure 1.
Chattecx Balance System (CBS).

At the time this study was undertaken, there had been few published studies regarding the test-retest reliability of the CBS within the hemiplegic population. Dickstein et al. showed the CBS to have good reliability in the nondisabled subject and moderate reliability for weight-bearing patterns in the patient with hemiplegia (13). Ghent et al. showed the reliability to be in the range of r=0.45–0.63 in nondisabled subjects (14). Irrgang et al. also showed the CBS to be reliable with nondisabled subjects (15). In order to use the balance system as an objective measure of determining progress in the patient with hemiplegia, the reliability of this system needs to be established for the patient popula-

tion. Once reliability has been established, the CBS would provide a valuable tool for investigating the effects of various balance training programs.

METHODS

Instrumentation

Evaluations were conducted on the CBS using software version 3.03. This system measures vertical reaction forces through four independent force transducers (footplates), one each for the heel and forefoot of each lower extremity (**Figure 2**). The sensitivity of the calibrated footplates is 0.5mv/N, with a linearity of 0.2 percent. Data are collected at the rate of 100 samples per second from each force transducer. The system calculates the positions of the center of pressure in both the anteroposterior (AP) and mediolateral (ML) axes as a proportion of the distance between the transducers. Center of pressure in an AP direction is defined by the CBS as the "center of balance in the y-axis" (COBY); center of pressure in a ML direction is defined by the CBS as the "center of balance in the x-axis" (COBX).

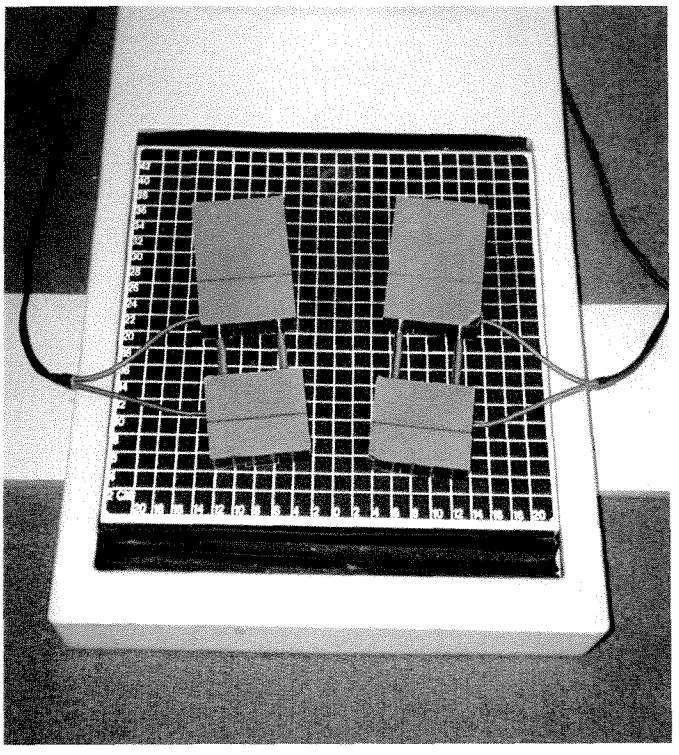

Figure 2.
Each footplate measures a single vertical force. They are located beneath the heel and forefoot on each side.

The system also calculates a "dispersion index" which is based on the amount of time the instantaneous center of pressure spends at different distances in any direction from the mean center of pressure. The CBS also allows for dynamic testing of weight-bearing patterns and balance, by the use of a moving platform that provides either angular rotation or linear translation.

Subjects

Twenty subjects (14 right hemiplegia, 6 left; 14 male, 6 female) with a mean age of 69.5 years (range 32–86), participated in this study. Subjects were volunteer inpatients or outpatients receiving physical therapy at Siskin Hospital for Physical Rehabilitation and were chosen on the following criteria: 1) medical diagnosis of hemiparesis secondary to a unilateral cerebrovascular accident (CVA), left or right, male or female; 2) no lower limb deformity or past history of any lower limb injury 12 months prior to data collection; 3) passive ankle dorsiflexion on the hemiplegic side of 0° or greater; 4) ability to stand independently with no assistive device for 30 seconds, and 5) no cognitive deficits that could interfere with following verbal instructions. Subjects all read and signed an informed consent form after the methods of the study had been verbally explained. This study was approved by the Human Subjects Committees at Siskin Hospital for Physical Rehabilitation, and the University of Tennessee at Chattanooga.

Test Protocol

Testing was conducted in the morning, prior to receiving any therapies, on three consecutive days. Day 1 was used to acquaint the patient with the balance system and test sequence. Although the test protocol was identical to that used on the second and third days, data from this day were not used for analysis. It was hoped that including this "practice day" might overcome the changes in response due to acclimatization. Days 2 and 3 were evaluation days, and the data obtained on these days were used for statistical analysis.

Subjects received three tests on each day, one static and two dynamic, each of which lasted 25 sec, followed by a rest period of 30 sec. The tests were administered in the same order and with the same verbal instructions each day. During the tests, a second tester was positioned directly behind the subject, out of view and not in direct contact with him or her, to provide assistance should the patient begin to fall. Such assistance was not needed for any of the subjects. For

the testing procedure, the positions of the two footplates were adjusted so that the subjects could stand on them comfortably with the platform in a level position (**Figure 3**). The locations of the footplates were recorded and reproduced in subsequent testing.

Subjects looked straight ahead at a blank wall, and received no visual feedback from either the video screen or the tester. If subjects touched the bar(s) during a test, the test was repeated. Subjects who could not perform the test without holding the bar were excluded, as we felt that touching the support bars, even once, could grossly change the results and invalidate the testing.

Figure 3.
Subject in test position on the CBS.

Subjects were first tested statically for 25 sec, after they had been told: "When I say ready, stand equally on both feet with your arms at your sides. Do not hold the bars unless you would fall otherwise. Keep your eyes straight ahead." Data were obtained and analyzed from the entire 25-second period.

Subjects were then tested dynamically, with the platform moving backward and forward (linear translation). This consisted of the platform moving plus and minus 25 mm from center position; this motion was performed at the instrument's 100 percent speed setting (0.1Hz, or 10 seconds per complete cycle). Subjects were told "The platform is going to move forward and backward. Stand equally on both feet with your arms at your sides. Stand as straight as possible and try to maintain good balance. Do not hold the bars unless you feel you would fall otherwise."

Subjects were then tested dynamically with the platform tilting forward and backward about a mediolateral axis (level to 4° upward tilt to 4° downward tilt) at the instrument's 100 percent speed setting (0.125Hz, or 8 sec per complete cycle). Subjects were told "The platform you are standing on is going to tilt up and down. Stand equally on both feet with your arms at your sides. Stand as straight as possible and try to maintain good balance. Do not hold the bars unless you feel you would fall otherwise."

Data Analysis

Intraclass correlation coefficients (ICCs) were calculated to describe the degree of intratester agreement for measurements obtained in this study. The ICC is a reliability coefficient obtained by analysis of variance, and is typically expressed as the variance associated with the raters divided by the sum of the variance associated with the targets and the error variance (16). There are several advantages to using the ICC in reliability studies, the most important being that it calculates the degree of agreement between two or more measurements, and not simply the association between them, which is measured by traditional correlational analyses such as the Pearson (17). The formula chosen was 3,1 of the ICC as described by Shrout and Fleiss (18), because only one judge evaluated the same population of subjects. As suggested by Portney and Watkins (19), an ICC value of 0.90 or greater was considered to be highly reliable, a value between 0.75–0.89 was considered moderately reliable, and a value below 0.75 was considered unreliable. Data were calculated for all subjects (n=20). ICCs were calculated

for COBX, COBY, and dispersion for all three testing protocols.

RESULTS

Table 1 shows the test results for the three measured variables (COBX, COBY, and dispersion index) in the three test conditions (static, linear translation, and angular rotation). These data are illustrated in **Figures 4–6** which also give the normal ranges for these variables, being the average of the results from two tests on 24 elderly subjects (ages 64–81) by Dickstein and Dvir (13), using a similar test protocol.

The ICC values for COBX, COBY, and dispersion index are given in **Tables 2–4** for the static, linear translation, and angular rotation test conditions, respectively. The static and angular protocols demonstrated similar reliability, and the linear protocol the lowest reliability. COBX was found to be highly reliable under the static testing condition (ICC=0.92) and moderately reliable under the angular (ICC=0.89) and linear (ICC=0.83) conditions. The values obtained for COBY were found to be unreliable (ICC<0.75) for all three testing protocols. The dispersion index was found to be moderately reliable for the angular (ICC=0.80) and static (ICC=0.75) testing protocols, and unreliable for the linear test (ICC=0.65).

DISCUSSION

The subject population used in this study consisted of patients with left and right hemiplegia, males and females, and a range of ages and clinical severities. It was not the intention of this study to give ranges for the measured variables, although these are summarized in **Table 1,** but rather to investigate the reliability of the method in a clinically important group. The numbers studied were not sufficient to report results for different subgroups of this population.

For each of the variables measured, a comparison was made between the results from a single trial on the second test day and the results of a single trial on the third day. This was thought to be a more clinically relevant test of reliability than comparing multiple tests made on the same day.

The variables tested in this study have the potential to be clinically relevant and useful in evaluating functional balance in the patient with hemiplegia. Our

Table 1.
Mean and standard deviation for results from 20 post-CVA patients for COBX, COBY and dispersion index, compared with data from Dickstein & Dvir (1993) for 24 nondisabled elderly adults.

	20 Post-CVA Patients		24 Elderly Adults	
	MEAN	SD	MEAN	SD
Static COBX	−0.1	19.5	9.2	16.3
Static COBY	0.9	13.1	11.7	9.6
Static Disp	8.4	3.4	4.9	2.3
Linear COBX	2.0	17.8	8.3	7.9
Linear COBY	5.8	14.0	19.0	11.9
Linear Disp	13.0	5.7	11.1	5.1
Angular COBX	−2.5	21.7	6.2	10.3
Angular COBY	4.6	15.9	13.5	9.5
Angular Disp	27.6	7.1	29.1	7.7

SD = standard deviation; COBX = center of pressure in the mediolateral direction; COBY = center of pressure in the anteroposterior direction; Disp = dispersion index.

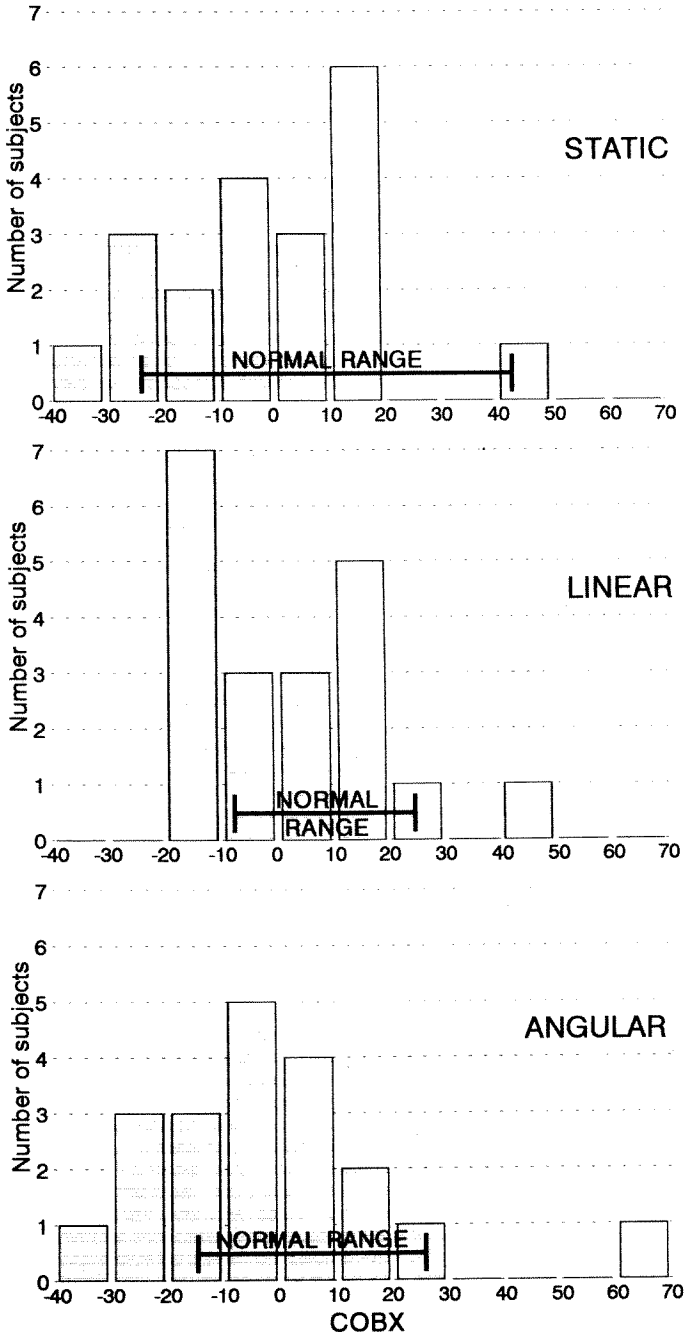

Figure 4.
COBX under three test conditions: histograms of numbers of subjects with test results in a given range. Normal range (mean ±2 SD) for variable in 24 elderly adult subjects from Dickstein and Dvir (13).

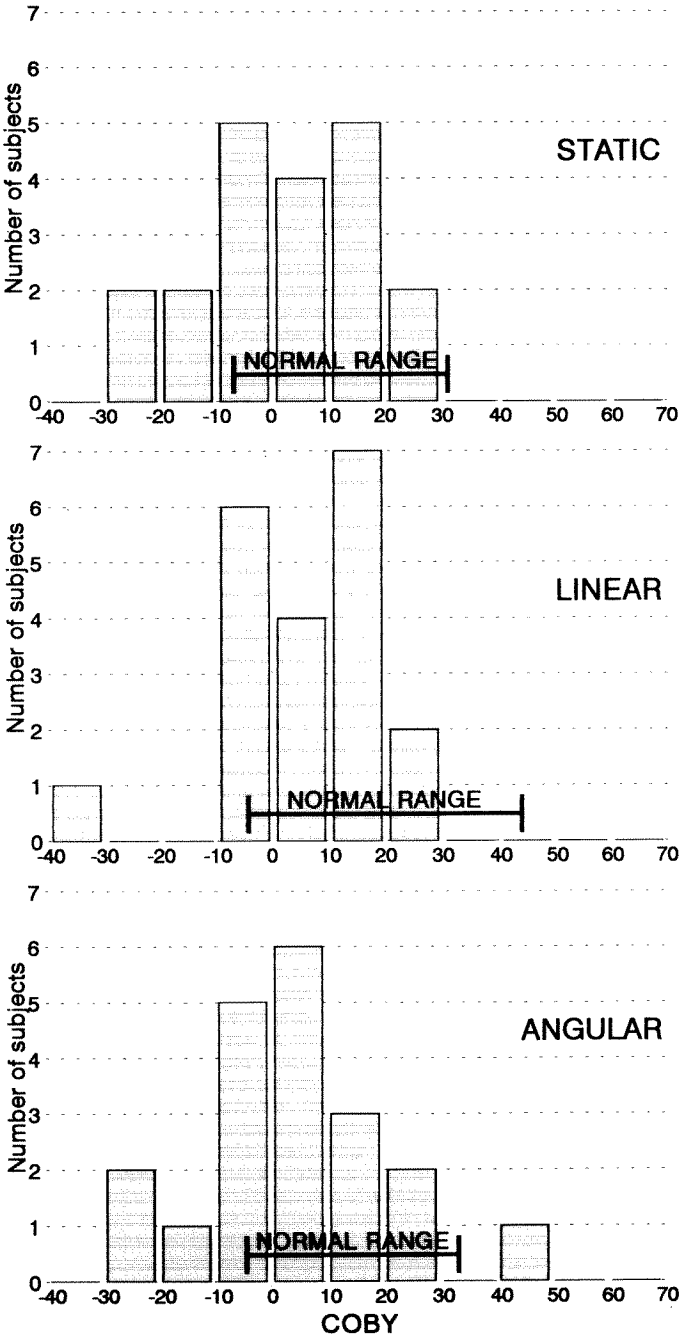

Figure 5.
COBY under three test conditions: histograms of numbers of subjects with test results in a given range. Normal range (mean ±2 SD) for variable in 24 elderly adult subjects from Dickstein and Dvir (13).

results showed that with a one-day training period and two testing days, of the nine variables studied, four were moderately reliable and one was highly reliable. The variable with the greatest overall reliability was COBX, the center of pressure in the mediolateral direction. This may be expected to be a relatively reliable measure, since the base of support is relatively wide, and adjustments for postural sway occur primarily

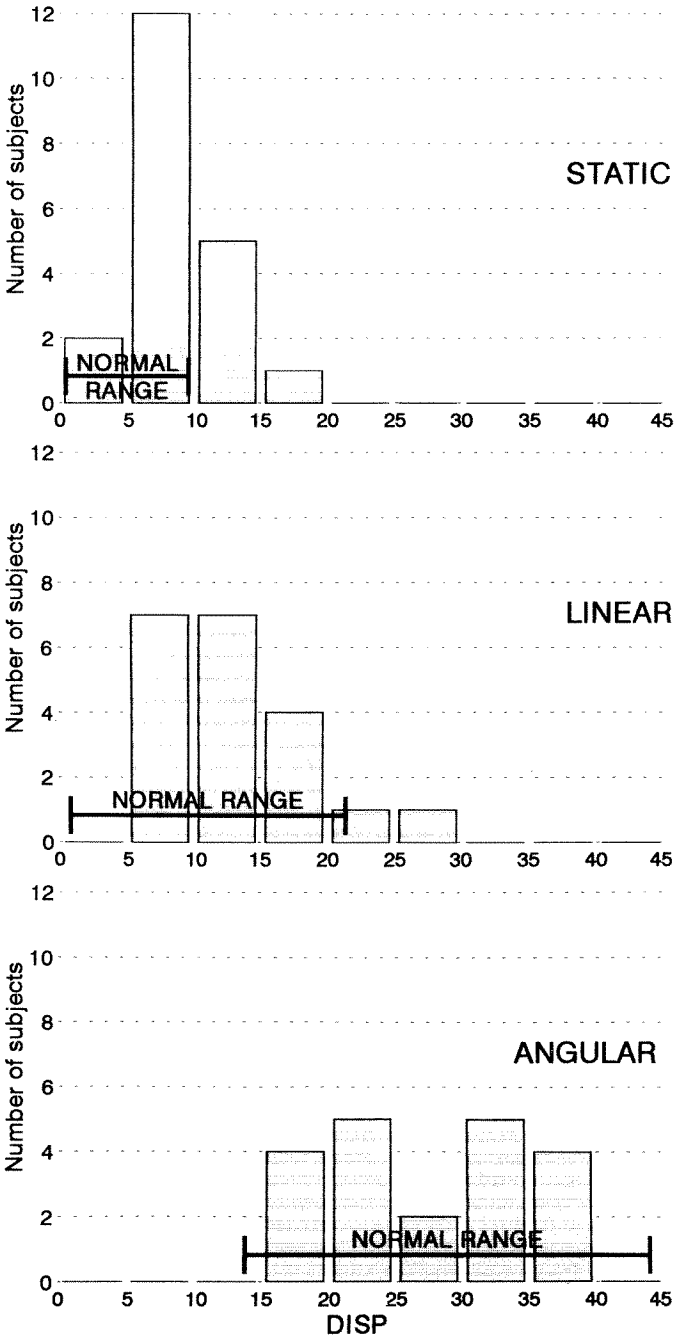

Figure 6.
Dispersion index under three test conditions: histograms of numbers of subjects with test results in a given range. Normal range (mean ±2 SD) for variable in 24 elderly adult subjects from Dickstein and Dvir (13).

at the hips, which are relatively close to the body's center of gravity. Since these patients tend to minimize load-bearing on the affected leg (11), changes in COBX should provide a useful indicator of progress in rehabilitation. The least reliable measurement was

Table 2.
Values of intraclass correlation coefficient for replicate testing (N=20). Static platform.

Measurement	Value	Significance
COBX	ICC = 0.92	$p < 0.01$
COBY	ICC = 0.58	$p < 0.01$
Dispersion	ICC = 0.75	$p < 0.01$

ICC = intraclass correlation coefficient; COBX = center of pressure in the mediolateral direction; COBY = center of pressure in the anteroposterior direction.

Table 3.
Values of intraclass correlation coefficient for replicate testing (N=20). Linear translation.

Measurement	Value	Significance
COBX	ICC = 0.83	$p < 0.01$
COBY	ICC = 0.46	$p < 0.02$
Dispersion	ICC = 0.65	$p < 0.01$

ICC = intraclass correlation coefficient; COBX = center of pressure in the mediolateral direction; COBY = center of pressure in the anteroposterior direction.

Table 4.
Values of intraclass correlation coefficient for replicate testing (N=20). Angular rotation.

Measurement	Value	Significance
COBX	ICC = 0.89	$p < 0.01$
COBY	ICC = 0.62	$p < 0.01$
Dispersion	ICC = 0.80	$p < 0.01$

ICC - intraclass correlation coefficient; COBX = center of pressure in the mediolateral direction; COBY = center of pressure in the anteroposterior direction.

COBY, the center of pressure in the anteroposterior direction. Not only is the base of support relatively short in this direction, but postural sway occurs about the ankle joint, which is physically separated by a large distance from the center of gravity of the body. In nondisabled individuals, postural stability is better in a medio-lateral direction, and postural corrections can be made at the hip about three times faster than at the ankle (20). As the dispersion index represents a combination of strategies employed in both antero-posterior and medial lateral directions, results tended to be intermediate in reliability between COBX and

COBY. Comparing the three test conditions, linear translation produced lower reliability than static testing or angular rotation, which were similar.

Even greater reliability may well have been obtained had the practice period exceeded 1 day. Additional testing needs to be done to determine the amount of training that is necessary to establish stability of behavior for all tests in this population. Inherent measurement errors from the system were probably insignificant when compared with errors caused by daily variance in subject status. We attempted to eliminate tester errors by using the same tester for all tests, and giving standardized instructions to the subjects. Errors due to subject variability were minimized by conducting the tests on three consecutive days at the same time each day. Subjects occasionally gave subjective feedback such as feeling they would not do well that day due to a poor night's sleep, or because the previous day had been a tiring one. Again, there were no corrections for these potential errors since they are likely to be present whenever clinical assessment of patients is attempted. Reliability could possibly have been improved through monitoring subjects' medications, which may have had an effect on balance over the 3-day testing period.

CONCLUSIONS

From a clinical standpoint, the CBS is a potentially useful tool for demonstrating changes in weightbearing during recovery from CVA. A prerequisite for such use is the establishment of measurement reliability in this patient population. This was the primary goal of the present study, from which the following conclusions can be drawn: 1) measurements of COBX were moderately or highly reliable in all testing situations using the above described protocol; 2) measurements of COBY were found to be unreliable in all three testing protocols; and 3) measurement of dispersion was found to be moderately reliable on the static and angular rotation tests, and unreliable on the linear test. Further research is necessary to determine what changes should be incorporated into the protocol to improve the reliability of COBY and dispersion measurements. From a clinical standpoint, those measures which were found to be the most reliable may prove to be useful in assessing the progress of patients with hemiplegia in their rehabilitation programs. Further studies would be needed to confirm this.

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