Static Stabilometry and Repeated Testing in a Normal Population

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Background: The purpose of the present study was to see if there is a learning effect of repeated static stabilometric testing, using a protocol suitable for testing postural control in narrow spaces, like hypo- and hyperbaric chambers. ***Hypothesis:*** Static stabilometry testing under normobaric conditions is objective and reproducible. With repeated testing, a learning effect may be observed. ***Methods:*** Four groups of healthy individuals were tested ten times under the same four acoustically and visually standardized and normobaric normoxic test conditions on a static balance platform. First, the subjects were asked to stand on a bare platform with the eyes open, thereafter with the eyes closed. This was repeated with a foam rubber mat placed on top of the balance platform. The time interval between the first and the last test sequence was 11 (10–13) days for the test subjects in group I (n = 22), 17 d for group II (n = 13), 31 (28–36) days for group III (n = 15) and 115 (49–193) days for group IV (n = 10). ***Results:*** Static stabilometry tests in a normal population are objective and reproducible. With repeated tests, a learning effect was observed. The learning effect was largest when standing on a foam rubber mat with eyes closed and when the time intervals between the tests were shortest. There was no difference in sway pattern or learning ability between tall and short test subjects, between subjects with heavy and light body weight or between the sexes.

Keywords: balance, human, learning effect.

POSTURAL CONTROL IS THE ability to maintain equilibrium and orientation in a gravitational environment. Important neurophysiological and clinical reasons for developing measurement tools to assess postural control in adults are described elsewhere (13,14). A static balance platform offers a simple, quantitative and reproducible method for evaluating the postural system under normobaric conditions (3,9,11). Previous investigations have demonstrated that a static balance platform is suitable for testing of postural control within the restricted space of hypobaric (8,10,19,24) and hyperbaric (1,2,6,20) chambers, and that the test procedures do not interfere significantly with normal chamber routines.

The goal of this study was to establish if there is a learning effect by repeated static stabilometric testing under normobaric normoxic conditions in a population of healthy subjects using a protocol suitable for testing postural control in narrow spaces. Previous studies have shown divergent results regarding the potential learning effect with repeated balance testing. In one study of 132 normal subjects, tests repeated over a period of 5 consecutive days yielded results with large variance within normal limits, but no systematic individual or group trends (5). In another study comprising 29 subjects, a decrease in postural sway was found with repeated testing, the improvement being very rapid initially, amounting to a reduction of 25% after the first 5 consecutive tests, with a total reduction of 31% over the 15 tests (12).

The postural system is highly complex, including feedback loops from several sensory qualities, e.g., the vestibular system, vision, proprioception from joints, tendons and muscles and superficial and deep tactile sense, communicating with the central nervous system. The vestibular system plays a central role in maintaining postural control and in keeping track of body position, as well as keeping an image stationary on the retina. In the sea, air or space, where other sensory stimuli such as vision, proprioception and tactile sense may be altered or even missing, misleading information from the vestibular system itself can cause spatial disorientation.

METHODS

The present investigation was a joint project between the University Hospital of Bergen and the Royal Norwegian Navy. The experiment was performed within the hyperbaric chamber complex at the Haakonsvern Naval Base in Bergen at surface pressure and in the laboratory facilities of the University Hospital.

All 60 subjects were healthy Navy recruits or hospital staff without any previous ear, balance or hearing prob-

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TABLE I. GROUP DESIGNATION.

Subjects	n	Female/Male	Average Age	Test Interval (d)
Group I	22	12/10	27 (23–46)	11 (10–13)
Group II	13	0/13	21 (20–23)	17
Group III	15	9/6	33 (22–54)	31 (28–36)
Group IV	10	4/6	28 (22–36)	115 (49–193)
TOTAL	60	25/35	28 (20–54)	35 (10–193)

Age and intervals are given as mean values (range in parenthesis).

lems. They were aged 20–54 (mean 27.6) yr. Informed consent to participate in the experiment was obtained from all subjects prior to testing, including their right to withdraw at any time. The project was approved by the Regional Ethics Committee.

Computerized stabilometry (posturography) used for documenting balance performance, is non-invasive and causes no discomfort. At 10 separate times (1 to 10), with different intervals, the subjects were instructed to stand still with their feet 7 cm apart and the arms along the sides on a static balance platform for each test sequence. Each sequence included four different conditions (I-IV). Each test condition lasted for 1 min. In the first test condition (Condition I) the subject was standing on a bare platform with eyes open (EO) looking at a small eye level target 2 m away. Condition II was with eyes closed (EC) on a bare platform. Then a 100-mm thick foam rubber mat, the exact size of the balance platform, was placed on top of it. The subject was asked to stand on top, first with the eyes open (EOF; Condition III), then with the eyes closed (ECF; Condition IV). The thickness of the mat when compressed by a standing person was reduced to approximately 16 mm at the heel, 18 mm under the arc of the foot and to 7 mm at the forefoot, depending on the weight of the subject.

No training, and only minimal instruction, was needed. The test was conducted under visually and acoustically standardized conditions.

The subjects were separated into four different groups (I–IV) according to the time interval between the first and the last of the 10 test sequences. To avoid interference with the daily and continuously running routines of the pressure chambers, we had to be flexible when designing the test intervals for the subjects. The time span, number of subjects and sexes are given for each group in **Table I.**

Any subjective complaints of dizziness were reported to an observer, and each test subject was observed while the test sequences took place.

A balance platform (Cosmogamma©, Bologna, Italy), measuring 40 × 40 × 8 cm, was used for data collection. The shift of the body's center of pressure (COP) at the soles of the feet during body sway was sensed by three mechanical-electrical transducers (strain gauges) in the platform and relayed to a computer (12 bit A/D resolution and 10 Hz sampling frequency). A monitor screen provided graphic and numerical presentations of different body sway characteristics, such as shift of the COP in the anteroposterior and lateral planes (**Fig. 1**).

To characterize the COP variable, we applied different sway parameters for measuring the amplitude and speed of sway performed by the subject while standing on the platform. These were the COP's path length, the mean sway speed in the anteroposterior and lateral planes, maximum and mean sway amplitude, sway frequency in the anteroposterior and lateral planes, and time spent by the COP within circles with different diameters. Since some of these parameters reflected the same postural stability change, we chose a few parameters which are commonly used in a clinical context for more detailed analyzes: a) the path length the COP described during each 1 min registration is determined by the gravitational force and the isometric muscular contractions, and thus related to the effort of the balance system in maintaining an upright posture; b) the mean speed of the correcting movements in the anteroposterior and lateral planes were chosen to evaluate the postural stability in the two planes; and c) the Romberg index (RI) is the ratio between measured parameters with closed and open eyes. It can be calculated for different parameters such as the path length and the speed described by the COP. Usually, body sway will increase when closing the eyes. Accordingly, the RI will usually have a numerical value > 1.

Within subjects analysis of variance (ANOVA) with repeated measures was used to examine the various parameters describing the effect of repeated testing on the postural system in the four groups of subjects. When statistical significance was found ($p < 0.05$), two-tailed Student's *t*-test for paired data were applied to evaluate the difference between the first and the following nine registrations.

To look for a possible effect of body weight, height, age and gender, we divided the test subjects into groups: highest and lowest, oldest and youngest, men and women, heaviest and lightest, and applied the Student's *t*-test. The relation between the time interval between the individual tests and the changes in path length was evaluated by standard correlation test.

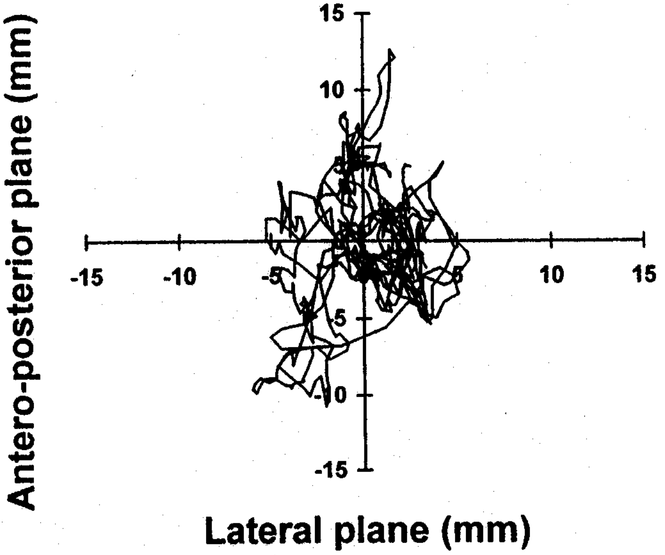

Fig. 1. Graphical presentation of the shift of the body's COP at the soles of the feet during posturography.

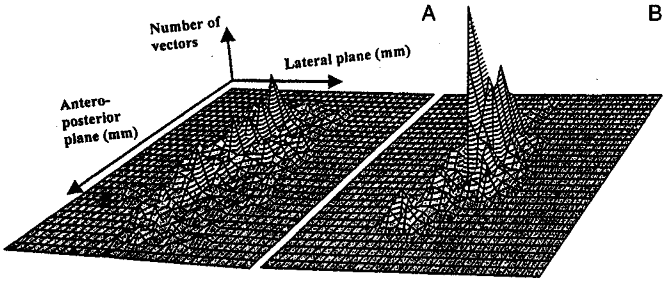

Fig. 2. 3-D distribution of the sway vectors during the first (A) and last (B) of 10 test sequences with EC for one of the subjects in group I. The "landscapes" are the histograms of the COP sway vectors (z-axis) in the lateral (y-axis) and anteroposterior (x-axis) plane.

RESULTS

During the balance platform tests none of the subjects reported any subjective dizziness and no unsteadiness was seen by the observer. Repeated balance platform registrations showed a learning effect reflected in a change in different body sway parameters. The learning effect was largest when standing on a foam rubber mat with eyes closed (ECF) and when the time span between test sequence 1 and 10 was shortest.

The learning effect on postural control was reflected in different parameters characterizing the body sway. **Fig. 2** shows an example of the relative relation between distribution of the sway vectors during the first (Fig. 2a) and last (Fig. 2b) of 10 test sequences with the eyes closed for one of the subjects in group I, tested over a time span of 10 d. The 3D "landscapes" are the histograms of the COP sway vectors in the lateral and anteroposterior plane (c.f. Fig. 1). Peak heights indicate the total numbers of the same vector. The last test (Fig. 2b) has the highest peak and smallest area of distribution, which reflect a higher postural control and thus indicating a learning effect.

The ANOVA statistics for repeated measures of the path length, lateral and anteroposterior speed for groups I–IV are summarized in **Table II**. A statistically significant ($p < 0.05$) learning effect was found for 9 of 12 sway parameters in group I, 5 of 12 parameters in group II, 3 of 12 parameters in group III and only 2 of 12 sway parameters in group IV. There was no significant learning effect for the EO condition for any of the groups.

Fig. 3 shows the mean path lengths and standard error described by the COP with EC at different test times (1 to 10) for all groups. In group I the path length was significantly reduced ($p < 0.0005$) for the late test registrations compared with the first registrations. No significant reduction was found for the other groups.

The RI for the path length, lateral speed and anteroposterior speed is presented in **Table III**. Significant values are seen for some of the RI conditions. Since the path length for the EC condition for group I showed a highly significant value and the EO condition for group I showed no learning effect, the relation between the two (EC/EO) was also significant.

There was no correlation between the time interval between individual tests and the change in path length or the different sway parameters and body weight, height, Body Mass Index (BMI) or age. Student's *t*-test on the 30 highest, oldest, heaviest and subjects with the largest BMI compared with the 30 lowest, youngest, lightest and subjects with the lowest BMI, between the first and the last test sequence, showed no difference in the learning potential between the groups. Furthermore, there was no difference in sway parameters or learning potential between the sexes.

DISCUSSION

Previous studies have shown that static stabilometry recordings of postural sway can be used to evaluate and quantify a dizzy patient's ability to receive and process vestibular, visual, and somatosensory-proprioceptive cues for postural stability (15,21,23,25). It can also be used to monitor patients with vestibular disorders and to document their responses to rehabilitation programs (15).

In a study of 30 healthy adults between 21 and 63 yr of age, sex-associated differences were highly significant for all sway components in the middle-aged and oldest age group in which men exhibited more sponta-

TABLE II. REPEATED MEASURES ANOVA WITHIN SUBJECTS EFFECT.

	Group I		Group II		Group III		Group IV	
	F(9,189)	P	F(9,108)	P	F(9,126)	P	F(9,81)	P
Path Length								
EO	1.261	0.261	1.037	0.415	1.447	0.175	0.895	0.534
EC	5.348	<0.0005	0.709	0.7	0.628	0.772	0.990	0.454
EOF	3.508	<0.0005	2.027	0.043	1.037	0.414	2.101	0.039
ECF	3.283	0.001	2.344	0.019	3.416	0.001	0.577	0.812
Lateral Speed								
EO	0.737	0.674	0.987	0.455	0.886	0.540	1.088	0.381
EC	5.616	<0.0005	1.680	0.103	0.701	0.707	1.547	0.146
EOF	2.925	0.003	3.208	0.002	1.815	0.072	2.616	0.010
ECF	4.656	<0.0005	2.982	0.003	3.793	<0.0005	0.507	0.865
AntPost Speed								
EO	0.930	0.5	0.665	0.738	1.928	0.054	0.752	0.660
EC	3.774	<0.0005	0.753	0.66	0.569	0.820	0.867	0.558
EOF	2.502	0.01	1.478	0.165	0.872	0.552	1.331	0.234
ECF	2.603	0.007	1.973	0.049	2.592	0.009	0.443	0.907

EO: Eyes open. EC: Eyes closed. EOF: Eyes open on foam rubber mat. ECF: Eyes closed on foam rubber mat. Values with $p < 0.05$ are shaded.

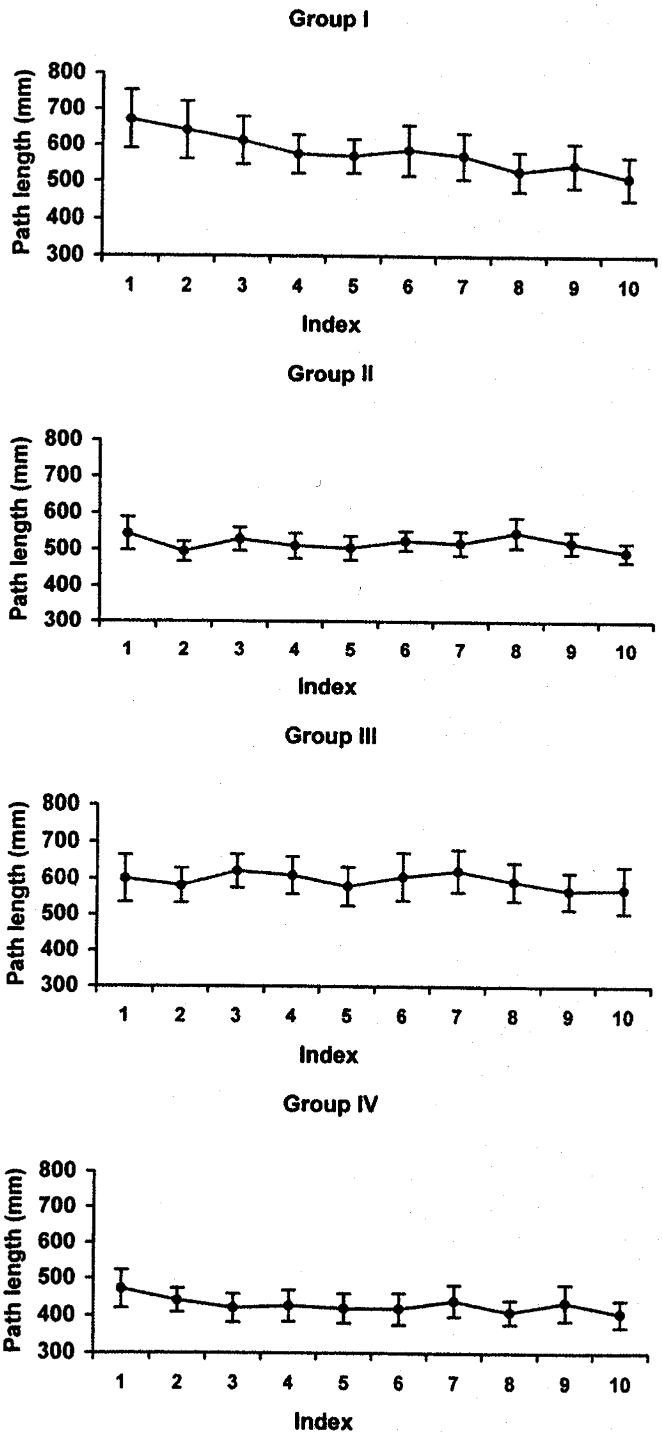

Fig. 3. The mean path lengths and standard error described by the COP with EC at different test times (1 to 10) for all four groups.

neous postural sway than women in the eyes open condition. With eyes closed these differences increased. In the eyes open condition, especially total sway and anteroposterior sway were increased, whereas in the eyes closed condition total sway and lateral sway were predominantly higher in men than in women. In the youngest age group no sex-related differences in postural sway were found (17). Other studies have shown the same effects of elderly subjects (4,7,18). We did not find any sex or age influence on sway parameters or learning potential. However, this may not necessarily be at variance with earlier studies because those were all designed to look into the effects of postural control related to age and therefore included subjects with a wider range of age than in our study. Although the age range in our subjects was from 20–54 yr, they were almost all concentrated around the mean age of 28 yr with only four subjects at an age of 38 yr or older. In all the above referred studies there were little differences in sway parameters or learning potential between the subjects in the lower age group, which is comparable to the age distribution in our material.

Our results are also in accordance with an earlier study performed on 132 normal subjects where no significant sex or age effect for adults aged 20 through 49 yr was demonstrated (5).

In our study there was no height or weight influence on sway parameters or learning potential. This is in accordance with a previous study comprising 152 subjects (9).

According to earlier findings, the positioning of the feet is not crucial in posturographic measurements provided the distance between the heels is determined, and the subject can choose the angle between the feet (16,22). We instructed our subjects to stand as comfortably as possible with their feet 7 cm apart and with an angle between the feet of their own preference.

There was a strong stabilizing influence of vision on postural control. With loss of visual references and a changed input of proprioceptive information from the sole of the feet (ECF), the learning potential was highest (Table II). The longer the time between tests the less likely it is to find a learning effect.

When all visual references are intact and the input of proprioceptive information from the soles of the feet are stable and easy to interpret, as when the subject is standing with open eyes on a bare platform (EO), postural control for normal subjects is easy, and no learning effect is seen no matter how frequently the test is performed.

For group III there were apparently no learning effect with the ECF condition. A learning effect was seen for EOF only. This may be due to the fact that the time intervals between the tests for this group were too long for obtaining a learning effect of a difficult task. However, opening the eyes may have reduced the difficulty sufficiently to place the situation within reach of learning.

In the present study the postural instability did not change in a systematic pattern for eyes closed compared with eyes open with repeated testing. Accordingly, the RI for most of the observed parameters did not change systematically.

Our test unit is small and can easily fit into a multiplace hypobaric or hyperbaric chamber. The test procedure is quick and needs little instruction. Thus it does not interfere significantly with a busy simulated diving or flying test schedule.

CONCLUSIONS

Static stabilometry tests in a normal population are objective and reproducible. With repeated tests, a learning effect is observed and the effect increases if the time

TABLE III. REPEATED MEASURES ANOVA WITHIN SUBJECTS EFFECT OF THE ROMBERG INDEXES.

	Group I		Group II		Group III		Group IV	
RI	F(9,189)	P	F(9,108)	P	F(9,126)	P	F(9,81)	P
Path Length								
EC/EO	2.206	0.023	1.193	0.307	1.351	0.218	0.193	0.994
ECF/EOF	0.918	0.51	1.440	0.18	2.320	0.019	1.332	0.234
Lateral Speed								
EC/EO	2.882	0.003	2.166	0.03	1.481	0.162	0.844	0.578
ECF/EOF	0.875	0.549	1.386	0.203	2.423	0.014	0.682	0.723
AntPost Speed								
EC/EO	1.227	0.280	1.585	0.129	0.916	0.514	0.868	0.557
ECF/EOF	1.283	0.248	1.659	0.108	2.075	0.037	1.279	0.261

RI: Romberg index. EO: Eyes open. EC: Eyes closed. EOF: Eyes open on foam rubber mat. ECF: Eyes closed on foam rubber mat. Values with $p < 0.05$ are shaded.

interval between the tests is shortened. This has to be taken into consideration in the interpretation of the results from studies involving repeated testing on a static platform.

There was no difference in sway pattern between tall and short test subjects, between young and old, between sexes or between subjects with heavy and light body weight.

Computerized stabilometry is a convenient posturograpic method. It is more sensitive than clinical observation and provides objectively quantifiable data. The test procedure is based on a small test unit, which easily can be placed in narrow chambers under different ambient pressures.

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