BRIEF REPORT

Repeatability of Static Posturography on the Follow-up of Vestibular Rehabilitation

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Background and Aims. We undertook this study to estimate the limits of agreement of repeated measures of static posturography on healthy adults and to assess the use of those limits on the interpretation of variations observed during vestibular rehabilitation of patients with chronic, peripheral vestibular disease.

Methods. Twenty healthy adults and 30 vestibular patients accepted to participate. At baseline and at weeks 4, 6 and 8 of follow-up, posturography was performed with the eyes open or closed, while adding or not a layer of foam rubber to the base of support. The Dizziness Handicap Inventory was administered to patients prior to rehabilitation and at week 8.

Results. At baseline, a difference between groups was observed on the sway area (p < 0.05). Healthy subjects showed no statistical difference among the four recordings (repeatability of measurements from 85–100%). Vestibular patients showed differences among the four recordings on the area and the length/average speed of sway (p <0.05); individual differences from baseline exceeding the limits of agreement were observed on the sway area. A decrease on the Dizziness Handicap Inventory (≥18 points) was observed on 19 patients, from whom 12 (63, 95% CI 53–73%) showed a change on the sway area (eyes closed) that was larger than the limits of agreement.

Conclusions. In healthy subjects, intra-subject repeated recordings of the area and the length/average speed of sway may be reliable at intervals of 4, 6 and 8 weeks. The sway area (without vision) may be a useful sway component, among others, to follow-up vestibular patients with chronic, peripheral disease during rehabilitation. © 2013 IMSS. Published by Elsevier Inc.

Key Words: Posturography, Repeatability, Vestibular rehabilitation, Vertigo.

Introduction

The ability to stand upright is important by itself and as a precursor to initiation of several daily life activities. Biomechanically, static balance can be defined as the ability to maintain the body’s center of gravity within the limits of stability determined by the base of support.

Recordings of the center of pressure by a static force platform are used to estimate body sway. To study how sensory information contributes to postural control, a common experimental technique is to remove or attenuate a particular sensory modality and measure how this changes sway behavior. This method is frequently used during follow-up of vestibular rehabilitation, at intervals of weeks or months (1–3). However, only a few studies have evaluated the reliability of posturography measures, mainly using correlation (4) and short intervals between recordings (5,6).

Reliability can be defined as the consistency of measurements or of an individual performance on a test (7). Because some amount of error is always present, reliability
could be considered as the amount of measurement error that has been deemed acceptable for the effective practical use of the measurement (7). In that case, reliability measured as the variability between repeated measures may show the degree of error (both random error and/or systematic error).

Many statistical tests have been proposed for the appraisal of reliability. Correlation coefficients reflect the consistency of the position within two distributions, without providing information about the degree to which repeated measurements vary and may be misleading (7,8). Although intra-class correlation avoids the problem of linear relationship being mistaken for agreement, it is dependent on the range of the measurement and is not related to the actual scale of measurement or to the size of the error which may be clinically allowable (8); it is affected by sample heterogeneity to such a degree that a high correlation may still mean unacceptable error for some analytical goals (7).

Among the methods to describe reliability, the limits of agreement represent the test-retest differences for 95% of a population (9). This method considers the differences between the measurements for each subject and meets the requirement of not depending on the range of the sample. The mean difference is the bias and the standard deviation of the differences is used to calculate the size of the difference likely to arise between measurements; –95% of differences will lie between −1.96 SD and +1.96 SD, which are called the limits of agreement (8,9). This method is used to assess the consistency of measurements and also helps to identify the magnitude of the difference that can be related to real changes on repeated measures.

The aims of this study were to estimate the limits of agreement of repeated measures (9) of static posturography on healthy adults and to assess the use of those limits on the interpretation of variations of the area and average speed of sway, observed during the follow-up of patients with chronic, peripheral vestibular disease who performed a standardized vestibular rehabilitation program frequently used in clinical practice (Cawthorne and Cooksey exercises) (10,11).

Materials and Methods

Subjects

After the study was approved by the Local Research and Ethics Committee, 50 subjects gave their informed consent to participate and were grouped as follows: Group I—20 healthy subjects (10 women/10 men), mean age 34.8 ± 7.6 years (standard deviation, SD < 50 years), and body mass index 26.07 ± 4.2. All subjects reported being in good health and were naive to posturography recordings. None had a history or clinical evidence of neurological, vestibular or orthopedic diseases. Group II—30 patients with chronic, peripheral, vestibular disease (17 women/13 men), mean age 38.9 ± 7.8 years (SD < 50 years), and body mass index 27.4 ± 3.2. By means of consecutive sampling, patients were considered eligible for inclusion in the study when symptoms related to their peripheral vestibular disease were present at least during the last 6 months, prior to participation in the study when they were < 50 years of age and had no evidence of concurrent diseases, with the exception of medically controlled high blood pressure in three cases. A clinical evaluation showed no evidence of neurological or orthopedic disease. Patients with benign paroxysmal positional vertigo, Menière’s disease or chronic middle ear disease were not included in the study. Because symptom duration was long, an accurate etiological diagnosis was not possible. The most frequent balance symptoms reported by the patients using a standardized questionnaire were (12): dizziness (96%), vertigo (90%), unsteadiness when changing posture (90%), unsteadiness when moving the head (93%) and unsteadiness in the dark (73%). Although 36% reported stumbling during walking, none reported falling. All participants had no spontaneous nystagmus, either in the light or in darkness (VNG15, Interacoustics, Copenhagen, Denmark), but abnormal results on a 30°C and 44°C caloric test. Directional preponderance was not evident in any case. Caloric test showed unilateral hypofunction in 90% of the patients (difference between right and left responses > 20%), 17 patients had an asymmetry ≥30% and bilateral hypofunction was observed in four patients (absent responses to 30°C and 44°C, no ice water test or rotational test were performed).

All vestibular patients practiced Cawthorne and Cooksey exercises (10,11) for at least 10 min twice a day for 8 weeks. This program is based on a series of exercises of increasing complexity, which include movements of the head, tasks requiring coordination of the eyes with the head, total body movements and balance tasks (Table 1). All patients were given written instructions with diagrams describing the exercises. They were instructed to keep practicing the same group of exercises for as long as the vertigo persisted and to progress to the next level whenever they could tolerate the exercises. Every 2 weeks, the same physician evaluated treatment compliance by performance and patient report. The Dizziness Handicap Inventory (13) was administered to all patients prior to treatment and at week 8 of follow-up.

Static Posturography

At baseline and at weeks 4, 6 and 8 of follow-up, body sway during quiet upright stance was recorded at a sampling rate of 40 Hz (analogical/digital conversion 16 bites) using a force platform with a resolution of 900 points/kg (Posturolab 40/16, Medicapteurs, Cedex, France). Each trial lasted 25.6 sec, the time standardized by the manufacturer of the platform in order to record 1024 data points. During this
period, subjects were asked to stand upright and barefoot on
the platform as still as possible with arms at their sides. The
same examiner gave similar instructions to each participant
and recordings were made under four conditions while add-
ing or not a layer of foam rubber (5 cm thick, density of 2.5
pcf, pounds per cubic foot) (14) to the base of support, with
the eyes open or closed: 1. hard surface/eyes open, 2. hard
surface/eyes closed, 3. soft surface/eyes open; 4. soft
surface/eyes closed. To describe the oscillation of the center
of pressure, during each condition the following measure-
ments were calculated using the software provided by the
manufacturer of the platform: the length (mm), the area
(90% confidence ellipse) (mm²), the average anterior-
posterior position of the center of pressure (mm), the
lateral-lateral position of the center of pressure (mm), the
average speed of sway (mm/sec) and the length as a func-
tion of the area.

Statistics
Comparisons were performed on the log-transformed area,
length and average speed of sway using repeated measures
ANOVA (among repeated recordings) and t test (between
groups). The significance level was set at 0.05. The limits
of agreement were calculated using the mean and SD of
the differences between measurements recorded at baseline
(9) relative to those recorded at weeks 4, 6 and 8 of
follow-up.

Results
Baseline
Comparison between healthy subjects and vestibular
patients showed consistent differences on the area of sway
under the four study conditions (t test, t values from −3.22
to −2.12, p < 0.05) (Figure 1) with no difference on the
length and the average speed of sway during conditions
1, 2 and 4, but just during condition 3 (t test, t values
−2.40 and −2.47, p < 0.05).

Follow-up
Group I. In healthy subjects, the four recordings and the
three estimated changes from baseline (at weeks 4, 6 and
8) showed no significant differences (ANOVA, p > 0.05),
and the repeatability of the measurements was between
85% and 100% (Table 2) for the four testing conditions.

Group II. In vestibular patients, the largest individual
changes from baseline were observed on the area of sway
at week 8 of follow-up. At that time, during the four testing
conditions, 33–56% of the patients showed an individual
change larger than the limits of agreement, which were
calculated from the recordings on healthy subjects

Discussion
In healthy adults, the repeated measures of postural sway
during quiet upright stance showed reliable results. These
results are in agreement with the within-day and between-
day reliability of several center of pressure-based measures.

<table>
<thead>
<tr>
<th>Table 1. Cawthorne and Cooksey exercises (27)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cawthorne and Cooksey exercises</strong></td>
</tr>
<tr>
<td>In bed or sitting</td>
</tr>
<tr>
<td>Eye movements – at first slow, then quick</td>
</tr>
<tr>
<td>Up and down</td>
</tr>
<tr>
<td>From side to side</td>
</tr>
<tr>
<td>Focusing on finger moving from 3 feet to 1 foot away from face</td>
</tr>
<tr>
<td>Head movements at first slow, then quick, later with eyes closed</td>
</tr>
<tr>
<td>Bending forward and backward</td>
</tr>
<tr>
<td>Turning from side to side</td>
</tr>
<tr>
<td><strong>Sitting</strong></td>
</tr>
<tr>
<td>Eye movements and head movements as above</td>
</tr>
<tr>
<td>Shoulder shrugging and circling</td>
</tr>
<tr>
<td>Bending forward and picking up objects from the ground</td>
</tr>
<tr>
<td><strong>Standing</strong></td>
</tr>
<tr>
<td>Eye, head and shoulder movements as before</td>
</tr>
<tr>
<td>Changing form sitting to standing position with eyes open and shut</td>
</tr>
<tr>
<td>Throwing a small ball from hand to hand (above eye level)</td>
</tr>
<tr>
<td>Throwing a ball from hand to hand under knee</td>
</tr>
<tr>
<td>Changing from sitting to standing and turning around in between</td>
</tr>
<tr>
<td>Moving about</td>
</tr>
<tr>
<td>Circle around center person who will throw a large ball and to whom it will be returned</td>
</tr>
<tr>
<td>Walk across room with eyes open and then closed</td>
</tr>
<tr>
<td>Walk up and down slope with eyes open and then closed</td>
</tr>
<tr>
<td>Walk up and down steps with eyes open and then closed</td>
</tr>
<tr>
<td>Bowling</td>
</tr>
</tbody>
</table>

*(Figure 3). However, for the length and the average speed of sway, the occurrence of individual changes from baseline exceeding the limits of agreement were scarce (6–17%) (Figure 3). These results were observed mainly when the eyes were closed. Interestingly, a decrease of the composite score on the Dizziness Handicap Inventory of at least 18 points at week 8 of follow-up was observed on 19 patients (63, 95% CI 54.7–71.3%), from whom 12 (63, 95% CI 53–73%) showed a change on the area of sway that was larger than the limits of agreement (eyes closed/hard surface).

Although most of the individual changes were not large
enough to exceed the limits of agreement, the analysis of variance on the follow-up evaluations showed significant differences among the four recordings on the area, the length/average speed of sway, mainly with the eyes closed (either on hard or soft surface) (ANOVA, F values for the area from 9.63–512 and for the length from 26.44–3223.77, p <0.05) (Figure 2), which were not observed on healthy subjects. Because the recording period was constant, the statistical analysis of the length and the average speed of sway were consistent with each other.*
of postural sway recorded from healthy adults (5,6). In this study, recordings at intervals of 4, 6 and 8 weeks were repeatable on both the area of sway and the length/average speed of sway. However, in this study, only the area of sway at baseline and follow-up showed different results between healthy subjects and vestibular patients. Additionally, in vestibular patients performing rehabilitation, the most frequent individual changes exceeding the limits of agreement (obtained from healthy subjects) were observed on the area of sway.

Different components of sway represent different parameters that may be not equivalent, but complement each other. Numerical measures of sway contour (area, perimeter, and complexity of sway shape) and radius length diagram can be used to describe the tendency of sway shape, whereas other quantitative sway measures represent the extent of sway amounts (15). In the clinical setting, the different components of sway may show different results depending on the circumstances and medical diagnoses of the patients. Acute blood alcohol concentration may affect average speed of sway more significantly than area of sway (16). Patients with bipolar disorder may have increased area of sway and decreased dynamical complexity (17). In patients with Parkinson disease, a combination of distinct characteristics of postural sway is recommended for quantitative posturography (18). In this study we observed that patients with vestibular disease during recovery showed a decrease on both the area of sway and the length/average speed of sway. However, after 8 weeks of follow-up, changes on area of sway were less variable than changes on length/average speed of sway. This result allowed us to observe more consistent differences from baseline on the area of sway than on the length/average speed of sway, which may not be attributable to the circumstances of measurement or the tool, but to rehabilitation.

Sway components may have a differential influence from a variety of intrinsic and extrinsic factors. In healthy subjects, age (19), gender and body mass index (20) may influence sway. Additionally, among other factors, the time of the day when the recordings are performed (21), the instructions issued to the subject (5,22) and the physical activity performed prior to the test (23) may also have an influence on the recordings. In this study, healthy subjects and patients were selected to prevent the variability related to their age, gender and body mass index. Also, recordings were performed at a similar time of the day, with no physical activity prior to the test, the same examiner gave similar instructions to each participant.
Table 2. Mean and SD of the difference from baseline of static posturography recordings after 4, 6 and 8 weeks of follow up of twenty healthy subjects, with the percentage of recordings within the limits of agreement (mean difference ±1.96 SD)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Variable</th>
<th>4 weeks</th>
<th>6 weeks</th>
<th>8 weeks</th>
<th>Limits of agreement</th>
<th>Repeatability</th>
<th>p ≤0.05*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard surface Eyes open</td>
<td>Length (mm)</td>
<td>−11.27 ± 4.145</td>
<td>95%</td>
<td>−5.57 ± 36.79</td>
<td>95%</td>
<td>−15.57 ± 54.27</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Area (mm²)</td>
<td>−3.74 ± 36.17</td>
<td>90%</td>
<td>9.11 ± 32.53</td>
<td>90%</td>
<td>−4.33 ± 31.81</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Average X&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>−0.28 ± 8.35</td>
<td>85%</td>
<td>−0.47 ± 7.82</td>
<td>100%</td>
<td>1.29 ± 6.94</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Average Y&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>7.12 ± 16.6</td>
<td>95%</td>
<td>7.35 ± 19.07</td>
<td>95%</td>
<td>1.6 ± 15.93</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Average speed (mm/sec)</td>
<td>−0.44 ± 1.62</td>
<td>95%</td>
<td>−0.22 ± 1.44</td>
<td>95%</td>
<td>−0.61 ± 2.12</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Length as a function of area</td>
<td>−0.03 ± 0.1</td>
<td>95%</td>
<td>−0.02 ± 0.09</td>
<td>95%</td>
<td>−0.04 ± 0.13</td>
<td>90%</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>Length (mm)</td>
<td>20.56 ± 79.81</td>
<td>95%</td>
<td>41.58 ± 82.57</td>
<td>100%</td>
<td>30.21 ± 94.47</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Area (mm²)</td>
<td>2.5 ± 72.66</td>
<td>95%</td>
<td>11.18 ± 97.44</td>
<td>90%</td>
<td>21.41 ± 62.77</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Average X&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>1.42 ± 6.21</td>
<td>95%</td>
<td>1.07 ± 6.89</td>
<td>100%</td>
<td>1.07 ± 7.52</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Average Y&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>6.24 ± 15.87</td>
<td>85%</td>
<td>5.51 ± 20.25</td>
<td>95%</td>
<td>1.91 ± 18.52</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Average speed (mm/sec)</td>
<td>0.8 ± 3.12</td>
<td>100%</td>
<td>1.62 ± 3.23</td>
<td>100%</td>
<td>1.18 ± 3.69</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Length as a function of area</td>
<td>0.03 ± 0.13</td>
<td>90%</td>
<td>0.07 ± 0.12</td>
<td>100%</td>
<td>0.04 ± 0.15</td>
<td>95%</td>
</tr>
<tr>
<td>Soft surface Eyes open</td>
<td>Length (mm)</td>
<td>−8.88 ± 35.2</td>
<td>95%</td>
<td>−18.55 ± 38.29</td>
<td>95%</td>
<td>−25.26 ± 45.7</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Area (mm²)</td>
<td>8.72 ± 35.6</td>
<td>95%</td>
<td>−3.93 ± 49.47</td>
<td>90%</td>
<td>−19.05 ± 53.06</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Average X&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>4.01 ± 12.89</td>
<td>100%</td>
<td>0.62 ± 10.48</td>
<td>95%</td>
<td>5.02 ± 10.41</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Average Y&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>−6.45 ± 15.31</td>
<td>95%</td>
<td>−0.78 ± 16.88</td>
<td>95%</td>
<td>−8.78 ± 18.74</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Average speed (mm/sec)</td>
<td>−0.35 ± 1.38</td>
<td>95%</td>
<td>−0.73 ± 1.5</td>
<td>95%</td>
<td>−0.99 ± 1.79</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Length as a function of area</td>
<td>−0.02 ± 0.08</td>
<td>95%</td>
<td>−0.03 ± 0.08</td>
<td>100%</td>
<td>−0.04 ± 0.1</td>
<td>95%</td>
</tr>
<tr>
<td>Eyes closed</td>
<td>Length (mm)</td>
<td>28.46 ± 122.94</td>
<td>90%</td>
<td>41.59 ± 130.81</td>
<td>100%</td>
<td>34.47 ± 126.39</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Area (mm²)</td>
<td>60.34 ± 119.91</td>
<td>100%</td>
<td>24.55 ± 161.79</td>
<td>95%</td>
<td>43.7 ± 138.81</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Average X&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>3.9 ± 12.44</td>
<td>100%</td>
<td>0.39 ± 10.97</td>
<td>95%</td>
<td>2.46 ± 13.44</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Average Y&lt;sub&gt;0&lt;/sub&gt; position (mm)</td>
<td>−3.76 ± 11.87</td>
<td>100%</td>
<td>−0.56 ± 16.93</td>
<td>100%</td>
<td>−6.64 ± 17.99</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Average speed (mm/sec)</td>
<td>1.11 ± 4.8</td>
<td>90%</td>
<td>1.62 ± 5.11</td>
<td>100%</td>
<td>1.35 ± 4.94</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>Length as a function of area</td>
<td>0.01 ± 0.17</td>
<td>95%</td>
<td>0.05 ± 0.17</td>
<td>100%</td>
<td>0.03 ± 0.18</td>
<td>95%</td>
</tr>
</tbody>
</table>

*<sup>X</sup> = Lateral-lateral average position of the centre of pressure.  
*<sup>Y</sup> = Anterior-posterior average position of the centre of pressure.  
*Repeated measures ANOVA.
and all patients performed a standardized rehabilitation program.

In patients with vestibular disease, significant body sway differences have been identified between healthy subjects and vestibular patients, depending on the particular diagnostic category, the sensory condition tested, and the particular sway component being measured (24). In this study the lack of differences between groups on the length/average speed of sway, observed at baseline, was accompanied with a low frequency of intra-individual changes exceeding the limits of agreement on the same measures. On the contrary, the consistent differences between the groups on the area of sway at baseline (even with the eyes open) was in agreement with the more frequent individual changes on this variable that exceeded the limits of agreement observed on the patients, even when inter-individual variability was larger than for the length/average speed of sway. These results suggest that it may be particularly useful to consider the area of sway on the follow-up of vestibular patients performing vestibular rehabilitation, among other components of sway. The finding of more consistent differences from baseline on vestibular patients during conditions with the eyes closed is in agreement with previous reports showing evidence that, after a peripheral vestibular lesion, recovery seems to be associated with reduction of visual dependence for postural control (2,25).

Figure 2. Median, 25th and 75th percentiles of the average speed of sway (A) and the area of sway (B) during the follow-up of 20 healthy subjects and 30 patients with chronic, peripheral vestibular disease. Recordings were performed at baseline (week 1) and at 4-, 6- and 8-week intervals during conditions 1–4 (eyes open/closed on hard/soft standing surface).
The main limitations of this study were as follows:

1) During the follow-up period, after 8 weeks of rehabilitation, the Dizziness Handicap Inventory showed improvement only in 63% of the patients, from whom 63% showed an individual change on the area of sway larger than the limits of agreement. Further follow-up may have shown higher percentages.

2) Lack of a control group for the vestibular rehabilitation—Due to clinical ethics, the follow-up of a group of vestibular patients with no rehabilitation was precluded. A learning effect could have then interfered with the results. In healthy subjects a learning effect has been shown mainly when recordings are obtained at short time intervals (26). The evidence that healthy subjects may have variable changes from baseline, either increase or decrease of sway, and the dissociation of results for the area vs. the length/average speed of sway, suggest that a possible influence of learning on the results would be partial.

3) The vestibular patients who participated in the study may not be representative of other patients with vestibular disease. However, the study was designed to minimize sources of variability, excluding older age as well as concurrent disease. Then, the results may not be applicable directly on other group of vestibular patients.

In conclusion, in healthy subjects, intrasubject repeated recordings of static posturography may be consistent at 4, 6 and 8 weeks. The area of sway (without vision) may be a useful component of sway, among others, to carry out a follow-up of patients with chronic, peripheral vestibular disease during rehabilitation.

Acknowledgments
Conflict of interests: None declared.

References


