Intrasession Reliability of Force Platform Parameters in Community-Dwelling Older Adults

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Objective: To investigate the intrasession reliability of center of pressure (COP) parameters calculated from force platform measurements.

Design: A cross-sectional study.

Setting: Gait and balance laboratory.

Participants: Community-dwelling healthy older adults (N=63) above the age of 62 years (mean age, 78.74y).

Interventions: Not applicable.

Main Outcome Measures: COP was estimated from a force platform, and the following parameters were calculated: (1) the total length of the COP displacement, (2) area of sway, (3) length of the COP displacement in the sagittal plane, and (4) length of the COP displacement in the frontal plane. Intraclass correlation coefficients (ICCs) were calculated by using 3 successive trials with 4 different test conditions. The test conditions were (1) normative standing with eyes open, (2) normative standing with eyes closed, (3) narrow stance with eyes open, and (4) narrow stance with eyes closed.

Results: The ICCs for the tests with eyes closed (.710–.946) were higher than those for tests with eyes open (.841–.945). The highest value was obtained for the vector sum of the COP during anteroposterior movement in narrow stance with eyes closed (.946). The value .710 was the lowest of all parameters and was an outlier for the narrow stance with eyes closed test, which was otherwise very reliable.

Conclusions: Eight of 16 calculated ICCs showed excellent reliability (> .90). They can be recommended for further use in clinical trials. Tests with closed eyes were more reliable than tests with eyes open. We recommend using eyes closed test conditions when assessing static balance control. For these tests, all the calculated ICCs were over .90, except for measurements of sway area.

Key Words: Aged; Posture; Rehabilitation; Reliability and validity.

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FALLS ARE A FREQUENT and serious problem for older adults. Approximately 1 in 3 people aged 65 years or over, living in the community, falls at least once during a period of 1 year. Among those living in institutions, the rate of falls is even higher. The frequency of falls increases with age, to over 50% for those aged 90 years and older. The risk of falls increases as the number of risk factors increases. Postural instability increases with aging and seems to be an independent risk factor for falls. Aging seems to enhance the severity of fall-related injuries, and these falls frequently lead to a loss of independence. Even falls that do not result in an injury are often the beginning of a vicious circle of fear related to loss of independence in activities of daily living, generally less activity, and higher risk of future falling. Clinical and/or functional balance tests can be used to estimate the risk of falling for a person, such as the Timed Up & Go test, the Tinetti Balance Scale, or the BBS. Although these tests have been evaluated for their reliability and have fared well, researchers must take advantage of new technologies as they become available. Force platform measures are particularly interesting for researchers because body sway can be described in several different parameters that describe aspects of balance control more accurately. Some of these parameters—for instance, mean speed of COP movement or the vector sum of COP movement—are difficult to measure using standard assessment.

Today there are a number of quantitative techniques used to measure balance. The force platform technique is among the tools most frequently used. It registers body sway by recording the vertical forces acting on the platform. Common systems use strain gauges. The COP is usually measured with either 3 or 4 strain gauges. This technique can be used in static conditions in which the platform is not moving, or dynamic conditions in which the subjects have to balance out perturbations. Such protocols are usually time-consuming, and the devices are usually secured to the ground and are very costly. They are ideal for laboratory research but might not be appropriate for screening of patients in a hospital setting.

Despite its frequent use, there are only a small number of studies investigating the reliability of this method. The reliability of force platform measurements should be determined before they are used as a potential predictor of falls. Force platform measurements can be subject to measurement errors that include 3 types of variability: intrasession (within a single session), intersession retest (between sessions), and interrater (between raters). Intrasession reliability is the immediate...
test-retest reliability, which is related to the random variability of the measurement per se. This can be subject to the inaccuracy of the measurement itself or variations in the performance of the subject and phenomenon tested. One aim of this study was to test the intrasession reliability of selected body sway parameters.

The study presented here tests the reliability of a cost-efficient, portable force platform, and a time-efficient protocol designed for hospital settings and screening of a large number of patients.

When testing elderly subjects, one must consider possible lack of endurance or strength. It was therefore necessary to develop a test that addressed these common problems. We chose short test durations. Another aim of this study was to develop a reliable test of static posturography that is time-efficient when used as a first-level screening tool for elderly persons.

This study was concerned only with the reliability of static measurements. Static posturography is an indicator of static postural control. However, the term static is misleading, because control of upright stance is dynamic in nature. A number of factors contribute to static stability, such as postural alignment, muscular tone, and sensory inputs from various systems. Problems with standing upright can also be related to a variety of diseases, such as diabetic neuropathy, neurologic impairments, or orthopedic impairments.

Many variables have been developed to quantify the ability to maintain an upright posture, such as the area of sway or the length of the path traveled by the COP. The length is usually divided into the amount of sway in the ML direction and the AP direction. Some of these measures have specifically been associated with balance disorders or falls. Some studies have shown that body sway increases with age, and some have found that the frequency of falls increases as sway increases. Therefore, postural variables are related to a decrease of control of quiet stance.

However, Patla et al indicate that measures of spontaneous sway during normative quiet standing are not an appropriate measure of balance control because older people may not be challenged by normative quiet stance. To challenge the participants, we included more difficult tests such as standing with eyes closed and with a reduced base of support.

METHODS

Participants

Sixty-three community-dwelling older adults (21 men, 42 women) from the Erlangen-Nürnberg area participated in this study. Their mean age was 78.74 years. Participants’ characteristics are presented in Table 1.

Subjects were considered community-dwelling if they lived independently in their own homes. They were recruited through a newspaper announcement.

Criteria for inclusion in this study were as follows: participants had to be 60 years or older, be able to walk 10m with or without a walking aid, be able to stand independently for 90 seconds, and be able to understand and follow verbal instructions.

Exclusion criteria were acute or subacute diseases of the cardiovascular or the respiratory system and/or severe cognitive impairment. Cognitive impairment was quantified with the Mini-Mental State Examination.

The study was approved by the Ethics Committee of the Friedrich-Alexander-University-Erlangen-Nürnberg. All subjects signed informed consent prior to the investigation.

Apparatus

Subjects were tested on a Satel® force platform containing 3 strain gauges set in a triangular position. It measures 480×480×65mm and weighs 12kg. The sensitivity of each sensor is certified to be .002% for a maximum load of 100kg a sensor. A variation of 9.8061N of the force applied to 1 strain gauge corresponds to a 50-mV variation of the output. The output range runs from 0 to 5V. The system uses a 12-bit analog-to-digital converter and a rejecter filter of 50Hz before the analog-to-digital converter.

A schematic representation of the force platform is shown in figure 1. Force data were sampled at 40Hz. The digital data were transferred via a universal serial bus port to a personal computer by customized software. The data were filtered with a 25-Hz low-pass second-order Butterworth filter to cancel out electric perturbations.

The primary outcomes resulting from this study were parameters describing the sway of the COP such as total length, vector sums, and sway area. Total length was measured in millimeters. This represents the path taken by the COP over the duration of the examination. Vector sums of the COP were measured during ML movements and the vector sums of the COP were measured during AP movements, respectively. The area of

![Fig 1. Schematic representation of force platform.](image-url)
sway, in millimeters, was calculated using a 95% confidence ellipse. Sway area represents the area covered by 95% of all COP positions during 1 measurement. The outcome measures are shown in figures 2 through 4.

Procedure

The test conditions (light, room temperature) were standardized before the tests, and all trials were conducted by the same 2 experienced researchers. Subjects stood quietly on the forceplate for 3 successive trials with 2 minutes of rest between trials. Subjects maintained each test position for 30 seconds. Data were recorded during the last 25.6 seconds.

All tests were performed with shoes removed. Subjects were told to look straight ahead with their heads erect and their arms resting at their sides, with instructions to maintain balance. Each trial consisted of 4 tests. In the first test, subjects remained in a standardized position (heel distance, 2cm; angle between feet, 30°) and looked straight ahead to a point 90cm in front of them (eyes open). This position was chosen to assure that subjects would be in the exact same foot position each time they were tested.

For the second test, subjects closed their eyes and remained in the same position (eyes closed). The third test was performed in the narrow stand position (ankles and toes touching) with eyes open. The last test was conducted in a narrow stand and with eyes closed. The narrow stand position was determined by a vertical red line in the middle of the closed test.

Statistical Analysis

All calculations were performed using SPSS® for Windows. We estimated the reliability of the parameters using ICC, based on a 1-way ANOVA that compares within-subject variability and between-subject variability. The ICC 2-way mixed-effect model (absolute agreement definition) described by Shrout and Fleiss21 was chosen because it considers random effects over time. For each ICC, the 95% CI was calculated to consider sampling variations. The ICC calculation is described in equation 1, where $MS_b$, $MS_r$, and $MS_e$ are the squared means of the 2-way ANOVA, $k$ is the number of trials, and $n$ is the number of subjects.

$$ ICC = \frac{MS_b - MS_e}{MS_b + (n - 1) MS_r + n (MS_b - MS_e)/k} $$

According to Walter et al22 and Donner and Eliasziw,23 30 subjects and 3 trials allow ICC estimations of .95 with a type 1 error of .05 and a type 2 error of .20. To contrast the variability of the measurements, $F_{max}$ tests were conducted.

RESULTS

The descriptive data are provided in table 2. The descriptive data show an increase of the mean area of sway, the mean length, and the mean AP sway for eyes closed conditions compared with eyes open conditions. Mean ML sway was higher for narrow stance conditions than referent standing.

The calculated ICC values for the outcome parameters are provided in table 3.

In total, 16 ICCs were calculated for 4 parameters across 4 conditions. Data sets from 63 subjects are available for the eyes open test, 61 for the eyes closed test, 62 for the narrow stance eyes open test, and 59 for the narrow stance eyes closed test.

The missing values resulted from subjects losing their balance during the tests. These were excluded from further analysis.

On average, the eyes closed test showed the highest calculated intrasession reliability across all parameters. AP sway in the narrow stance eyes closed test was the most reliable parameter (.946), whereas in the same test, the sway area was the least reliable, having only moderate reliability (.710).
The total length of COP movement showed better reliability for the eyes closed and narrow stance eyes closed tests than for the eyes open and narrow stance eyes open tests.

The ICCs obtained for the blindfolded tests (eyes closed, narrow stance eyes closed) showed higher reliability than the eyes open and narrow stance eyes open tests.

ML sway was the most reliable parameter in the eyes open test, area of sway in the eyes closed test, and AP sway in the narrow stance eyes open and narrow stance eyes closed tests.

AP sway was the worst parameter in the eyes open test, ML sway in the eyes closed test and the narrow stance eyes open test, and area of sway in the narrow stance eyes closed test.

Fmax test results are provided in table 4.

### DISCUSSION

The intrasession reliability of 4 COP measures was tested with an ANOVA-based ICC model. Four different test conditions were used. We found that AP sway was the most reliable COP variable. We further found that reliability increased when subjects were asked to close their eyes and to close their eyes while maintaining the narrow stance position. Except for area of sway, all parameters showed excellent reliability during these 2 tests. All parameters showed good to excellent reliability. To test homogeneity of variance, Fmax tests were conducted. Fmax tests showed reliable differences in variability across all 4 parameters. This indicates the influence of the test position on the parameters. The 95% CIs were examined for overlap to assess for statistically reliable differences between the ICCs. The 95% CI of the ICC for narrow stance eyes closed area is an outlier, falling beneath the 95% CIs for the ICCs for the other 3 test conditions. The 95% CI for narrow stance eyes closed area only overlaps with the 95% CI for eyes open area and ML sway, and narrow stance eyes open area and ML sway. Other outliers are the 95% CI for eyes open AP sway and narrow stance eyes open ML sway, which fall beneath the 95% CIs for eyes closed area, narrow stance eyes closed length, and narrow stance eyes closed AP sway. We therefore recommend excluding these measures in future research and assessment.

Previous research has shown that selected force platform parameters are associated with the incidence of falls in elderly persons. These are parameters associated with AP and ML COP movement as well as sway area. For recurrent fallers, the amount of ML sway (in centimeters) with eyes open and sway area ellipse were higher than for nonfallers or persons falling only once. A higher amount of ML movement during dual task conditions (a simple mathematical test performed during a balance test) was predictive of injurious falls. We therefore investigated the reliability of these selected parameters. Our results show that ML sway, AP sway, and area of sway are reliable parameters.

However, other studies found no association between force platform measurements and falls. We assessed the reliability of selected parameters because poor reliability might be one explanation why some studies found no association between posturography and falls. Our results and previous studies show that posturography can be a reliable measurement tool. Other studies regarding the reliability differ in terms of device used, participants, measurement protocol, and parameters. Because of methodologic differences and the different results regarding the validity of force platform measures, we think that each protocol of posturography has to be evaluated for its reliability. The next step will be to analyze the validity of the presented protocol in an ongoing study.

This study shows reliable results of static posturography measured by a small portable platform. The duration of the presented test was approximately 10 minutes. The time efficiency of this test makes the procedure suitable for hospital settings and for screening of larger numbers of patients. The mean area of sway, the mean length, and the mean AP sway increased when the participants were asked to close their eyes. This finding is similar to previous research. These results may be the result of a reduced function of the vestibular organs.

### Table 2: Means of 3 Trials

<table>
<thead>
<tr>
<th>Measure</th>
<th>Eyes Open (N=63)</th>
<th>Eyes Closed (n=61)</th>
<th>NEO (n=62)</th>
<th>NEC (n=59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean area (mm²)</td>
<td>259.14±211.54</td>
<td>602.09±668.53</td>
<td>491.94±233.11</td>
<td>1372.59±1462.47</td>
</tr>
<tr>
<td>Mean length (mm)</td>
<td>426.89±178.61</td>
<td>711.96±413.07</td>
<td>625.64±250.09</td>
<td>1153.03±561.46</td>
</tr>
<tr>
<td>Mean ML sway (mm)</td>
<td>239.32±94.35</td>
<td>357.51±179.79</td>
<td>429.66±162.31</td>
<td>772.61±343.31</td>
</tr>
<tr>
<td>Mean AP sway (mm)</td>
<td>298.96±141.18</td>
<td>534.25±351.16</td>
<td>360.57±171.98</td>
<td>687.53±396.75</td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± SD.
Abbreviations: NEC, narrow stance eyes closed; NEO, narrow stance eyes open.

### Table 3: ICCs and 95% CIs for the Average of 3 Trials

<table>
<thead>
<tr>
<th>Measure</th>
<th>Eyes Open (N=63)</th>
<th>Eyes Closed (n=61)</th>
<th>NEO (n=62)</th>
<th>NEC (n=59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>.873</td>
<td>.945</td>
<td>.878</td>
<td>.710</td>
</tr>
<tr>
<td>95% CI</td>
<td>.863–.920</td>
<td>.917–.965</td>
<td>.814–.922</td>
<td>.553–.818</td>
</tr>
<tr>
<td>Length</td>
<td>.885</td>
<td>.933</td>
<td>.886</td>
<td>.945</td>
</tr>
<tr>
<td>95% CI</td>
<td>.825–.927</td>
<td>.891–.959</td>
<td>.826–.927</td>
<td>.915–.966</td>
</tr>
<tr>
<td>ML sway</td>
<td>.899</td>
<td>.918</td>
<td>.841</td>
<td>.933</td>
</tr>
<tr>
<td>95% CI</td>
<td>.844–.936</td>
<td>.874–.948</td>
<td>.758–.899</td>
<td>.896–.958</td>
</tr>
<tr>
<td>AP sway</td>
<td>.843</td>
<td>.926</td>
<td>.907</td>
<td>.946</td>
</tr>
<tr>
<td>95% CI</td>
<td>.763–.900</td>
<td>.874–.956</td>
<td>.859–.941</td>
<td>.915–.967</td>
</tr>
</tbody>
</table>

Abbreviations: NEC, narrow stance eyes closed; NEO, narrow stance eyes open.
because of the normative, physiologic aging processes or pathology.31 As a result of this loss, the vestibular organ might not be able to function as a reference system with which the other systems can be calibrated,32 resulting in poor postural control. Mean ML sway increased when the subjects had to remain in the narrow stance position (narrow stance eyes open, narrow stance eyes closed) compared with eyes open and eyes closed. The reliability increased when the subjects were asked to close their eyes and when they were asked to close their eyes while maintaining the narrow stance position. We found that eyes closed proved to be the single best test, because all variables showed excellent reliability. In the narrow stance eyes closed test, only the area of sway did not show excellent reliability. This is an important finding because comparable studies use only eyes open methods.12,28 On the basis of these results, including tests under blindfolded conditions should be recommended when using static posturography as a screening device for elderly persons. Lee and Lishman33 found increased reliance on visual inputs when adults were just learning a task. Eyes closed, narrow stance eyes open, and narrow stance eyes closed are positions that were unfamiliar for most participants. Participants had to adapt to these new test positions. Possibly it was easier for them to adapt when vision was intact (narrow stance eyes open) than when it was removed (eyes closed, narrow stance eyes closed). This might cause a smaller variability between the first and the consecutive trials for the eyes closed and the narrow eyes closed test, resulting in higher ICCs and 95% CIs. To evaluate the adaption to these test conditions and to describe the possible changes in the balance strategies, further research should be conducted, including kinematic analysis of body segments and changes in balance strategy over several trials.

Eyes closed and narrow stance test conditions are used in many screening tools, such as the Tinetti Balance Scale8 and BBS.8 The results show that our protocol of static posturography gives reliable measurements for these items. One implication of our findings is the recommendation to use clinical scales and therefore, we chose a broad spectrum of persons for representative sample of community-dwelling elderly persons, and therefore, we chose a broad spectrum of persons for inclusion in this study. Because of the broad spectrum of subjects, we achieved higher external validity. The good reliability of the results shows that even a wide range of subjects does not affect the reliability of static posturography.

Other comparable studies use a larger number of posturography variables.27,41 It would have been beneficial to use mean speed of sway or fractal dimensions of postural sway variables. Then it would be easier to compare our outcome with other studies. In a follow-up study we plan to assess the reliability of other measures of postural sway, using the same protocol.

### CONCLUSIONS

This study established the reliability of 4 parameters of postural sway, across 4 test conditions. Eight of 16 calculated ICCs showed excellent reliability (> 0.90). They can be recommended for further use in clinical trials. Eyes closed conditions showed better reliability than eyes open conditions. We recommend using eyes closed test conditions when assessing static balance control. For these tests, all the calculated ICCs were above .90 except measurements of sway area. The factors influencing the reliability of eyes closed conditions must be assessed in future studies. The equipment is lightweight and need not be fixed in-ground, making it more suitable for hospitals than expensive in-ground force platforms. The dura-
tion of the presented test is about 10 minutes. The test procedure is time-efficient, which makes it suitable for hospital settings and for screening large numbers of patients.

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References


Suppliers

a. Satel, Rue du Linouzins, Blagnac, France 31700.