Towards objective quantification of the Tinetti test

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Summary

The Tinetti test is a widespread test for assessing motor control in the elderly, which could also be usefully applied in neurology. At present it uses a qualitative measurement scale. As a first step towards its objective quantification, trunk inclination was measured during the test by two inclinometers and quantified by descriptive parameters. The 95th or 5th percentiles of parameter distributions in normal subjects (n=150) were taken as limits of normality, and parameters computed on 130 institutionalised elderly people were compared to these limits, to test the parameters' discriminatory power. The distributions of many parameters were statistically different in normal subjects and patients. These results suggest that this approach is a promising tool for objective evaluation of the Tinetti test.

KEY WORDS: Elderly; measurement; risk of fall; standard; Tinetti test.

Introduction

In order to maintain postural stability when standing and/or walking, the brain must rapidly process signals from the visual, vestibular and somatosensory systems. Because balance depends on multiple sensory inputs, it can deteriorate when one or more of these systems fail. The combined loss of sensory signals from several systems has been proposed as a common cause of imbalance (1). Some investigators have suggested that imbalance is a normal aging phenomenon that is most likely the result of multiple conditions (2,3). In fact, disequilibrium in older people may have a number of different causes. Balance can be compromised by a decrease in lower extremity range of motion, muscle flexibility, strength, endurance and general deconditioning. Poor or abnormal posture can also contribute to balance impairment and may be a symptom of a localised central nervous system lesion (4). The interest in balance assessment in neurology is well known; indeed, a quick search in medical databases available on the Internet found dozens of papers concerned with posture and neurology. Balance control is most often assessed by conventional posturography, although the Tinetti test (5) offers a possible alternative. The Tinetti test is a widespread test for assessing motor control in the elderly, but it could be usefully applied in other fields, too, including neurology. For instance, it has been used in the evaluation of Parkinson's disease (6) and of acute stroke patients (7). The Tinetti scale has 14 items (overall score up to 24) assessing balance and 10 (overall score up to 16) assessing gait. It thus gives a maximum score of 40, with higher scores corresponding to better performance (5,8). It is the most widely used of many other similar assessment scales (9-11). However, it still has some limitations, albeit shared by all the other measurement scales of its genre:

i) its results depend on subjective judgments, which means that it cannot provide internationally standardised measurements;
ii) it is subject to floor-ceiling effects;
iii) it uses a scale of integers, which limits its resolution.

On the other hand, in geriatrics, the Tinetti test has been shown to help in the clinical approach to the patient. For instance, a recent study demonstrated that it does have predictive value for the identification of subjects at risk of falling, although “research should be done into improving performance” (8). We thus endeavoured to overcome the above measurement limitations and to improve the performance of the test. Indeed, an ad hoc measurement instrument has been developed that allows objective quantification of a subject's performance during the balance items of the Tinetti scale (12). This system (Evaluation System for the Tinetti Test, ESTT) was designed according to criteria of technical simplicity, cost-saving, adaptability, ease of use and versatility, and starting from the assumption that it must be easy to use and to move, manageable by inexpert personnel, and usable in centres, such as residential nursing homes, that do not have large financial resources.

The aim of this paper is to summarise the principle and the characteristics of the ESTT and to present some results obtained with its use. Moreover, it will be outlined how this system, providing a tool for the objective evaluation of a subject's performance according to interna-
tional measurement standards criteria, overcomes the limitations of conventional evaluation scales. A normative basis for the measurements made using the ESTT is also proposed. These two points are both consistent with quality system requirements of the Joint Commission on Accreditation of Healthcare Organisations, which has called for the achievement of consensus on the most recently developed tools, according to international measurement standards criteria.

Materials and methods

The ESTT consists of (Fig. 1): i) a normal wooden seat with pressure sensors to register the presence of the patient, and ii) a two-inclinometer system, mounted on an adjustable support and placed on the patient’s chest at sternum level, which measures the frontal and lateral inclination of the upper half of the body.

The pressure sensors and the inclinometers are connected, via appropriate conditioning circuits, to a commercial acquisition board inserted into the bus of a PC. The data management, storage, and visualisation and processing of the signals from the patient were developed in the LabVIEW® (National Instruments, USA) environment.

The hardware and software characteristics of the ESTT have been described in detail elsewhere (12), and only a short summary is given here. The main nominal characteristics of the inclinometers were: measurement range ± 90°, linearity range ± 30°, linearity ± 1% FS, tilt sensitivity better than 0.03°, bandwidth of DC to about 4 Hz, weight 35 g. They were placed on a polycarbonate support and oriented with their planes of maximal sensitivity perpendicular to each other. When the system was placed on the subject’s chest these planes were parallel to the subject’s medial (xz) and frontal (yz) planes so as to separately measure antero-posterior and right-left trunk inclination. Overall accuracy and repeatability of the measurement system “in the field,” i.e., when placed on the subject, were, in usual test conditions and with reasonably careful application of the system to the subject’s chest, estimated to be better than 2% and in the order of just a few percent (7.5% in the worst case), respectively. Signals from the inclinometers and pressure sensors were A/D converted at the frequency of 50 samples/s using 12-bit words.

In order to establish the normative data set, measurements were taken on a control sample of 150 healthy subjects aged 20 to 70 and clustered into groups of 30 subjects for each decade. Subjects in this control sample were required not to present any type of articular or functional limitation nor any neurological deficit that might interfere with their execution of the test.

For a first assessment of the system’s ability to discriminate abnormal from normal performance, measurements were repeated on two samples of elderly institutionalised people, one from a geriatric department (sample A: 71 patients, mean age 77.5, range 56 to 91), the other from an old people’s home (sample B: 59 patients, mean age 85.4, range 60 to 99). Both were located in northern Italy. The inclusion criteria for these two samples were ability to understand the instructions given by the examiner and to carry out autonomously the Tinetti scale manoeuvres related to balance. No other inclusion criteria were considered. In particular, no attention was paid to the composition (in terms of pathologies represented) of the sample. In fact, our goal was not to study the response to the Tinetti scale in a given pathology, but rather to test the possibility of discriminating normal from abnormal behaviour, of whatever origin, taking the measurements as a starting point.

The test required the subjects to repeat a subset of the Tinetti scale manoeuvres related to balance. This subset is the one usually adopted for screening purposes in Italian geriatric units.

The signals from the two inclinometers, representing backwards-forwards and lateral inclinations of the trunk, were processed in order to compute numerical parameters (amplitude, duration, velocity, …) quantifying the pattern of the subject’s movement in each phase of the test. We considered the 7 manoeuvres and 20 related

![Fig. 1 - The instruments used in the ESTT.](image)

A = personal computer; B = chair with pressure sensors; C = two-inclinometer system; AI = analogue input; DO = digital output.
parameters listed, respectively, in the first and second columns of Table I (12).

The parameter values of all the subjects, grouped into homogenous samples (samples A, B and controls subdivided by decades), were evaluated and submitted to statistical analysis.

First, the distributions of the values of each parameter in the various decades represented in the control sample were compared to each other. Then, the distributions of these parameters, relating to normal subjects, were compared to the corresponding distributions in samples A and B, as a first step in testing the capacity of each parameter to discriminate between different behaviours or performances. On a qualitative level, the discriminatory power of a parameter is shown by the degree of separation between the distribution of its values in different samples. In order to quantify this separation in a simple way, the median and interquartile interval (interval between the 25th and 75th percentiles) were calculated for each parameter and each sample.

Furthermore, for the parameters that measured the amplitude of postural sway, the duration of the different movements, the inclinations of the trunk and the number of steps needed to effect a full turn on the spot, the value corresponding to the 95th percentile of the normal distribution was computed, as was the percentage of patients whose performance was worse, i.e., in whom the parameter value was higher than the 95th percentile. For the parameters measuring the inclination velocities of the trunk, the 5th percentile of the normal distribution and the percentage of patients who had a velocity lower than that percentile were evaluated. The decision to use the 95th (or 5th) percentiles was made in an attempt to filter out possible outliers by disregarding the maximum (or minimum) values, which may well be produced by artefacts. Thus, the 95th (or 5th) percentiles of the parameter distributions in normal subjects were chosen as the cut-offs, or thresholds, against which the performance of the elderly subject can be deemed normal or otherwise. The use of this simple method is justified by the fact that only a judgment on the normality of the individual performance, and not a statistical comparison between groups, was sought.

Results

First of all, we considered the results of the control group (normal subjects) divided by age decades. A first comparison between the mean and standard deviation

Table I – Medians (and interquartile intervals) of the parameters quantifying the performance of each subject in the control group and in samples A and B, normality thresholds (see text), and percentage of off-threshold patients (Rejection ratio).

<table>
<thead>
<tr>
<th>Tinetti test manoeuvre</th>
<th>ESST parameter</th>
<th>Unit</th>
<th>Group A</th>
<th>Group B</th>
<th>Control</th>
<th>Threshold value</th>
<th>Rejection ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting balance</td>
<td>Lateral sway S.D.</td>
<td>°</td>
<td>0.77 (0.72-0.90)</td>
<td>0.75 (0.7-0.84)</td>
<td>0.76 (0.73-0.8)</td>
<td>0.89</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Antero-posterior sway S.D.</td>
<td>°</td>
<td>0.82 (0.76-0.97)</td>
<td>0.79 (0.74-0.89)</td>
<td>0.79 (0.74-0.84)</td>
<td>0.96</td>
<td>24</td>
</tr>
<tr>
<td>Arising from chair</td>
<td>Forward inclination duration</td>
<td>s</td>
<td>1 (0.4-2.13)**</td>
<td>1.03 (0.4-2.54)**</td>
<td>0.32 (0.26-0.44)</td>
<td>0.70</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>Straightening duration</td>
<td>s</td>
<td>2.14 (1.3-2.96)**</td>
<td>2.64 (1.13-5.28)**</td>
<td>0.84 (0.7-1.18)</td>
<td>1.96</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Overall duration</td>
<td>s</td>
<td>3.60 (2.25-5.08)**</td>
<td>4.11 (2.37-7.1)**</td>
<td>1.32 (1.1-1.74)</td>
<td>2.43</td>
<td>70</td>
</tr>
<tr>
<td>Mean fwd inclination velocity</td>
<td>°/s</td>
<td>32.1 (15.3-87.2)**</td>
<td>34.1 (11.7-96.6)**</td>
<td>116 (81.2-160)</td>
<td>45</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Mean straightening velocity</td>
<td>°/s</td>
<td>16.8 (9.3-27.5)**</td>
<td>13.8 (5.9-27.8)**</td>
<td>48.2 (36.3-63.4)</td>
<td>18</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Immediate standing balance</td>
<td>Lateral sway S.D.</td>
<td>°</td>
<td>0.89 (0.8-1.09)</td>
<td>0.8 (0.76-1.12)</td>
<td>0.86 (0.8-0.96)</td>
<td>1.53</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Antero-posterior sway S.D.</td>
<td>°</td>
<td>1.08 (0.9-1.31)**</td>
<td>0.96 (0.82-1.18)</td>
<td>0.92 (0.84-1.08)</td>
<td>1.36</td>
<td>19</td>
</tr>
<tr>
<td>Standing balance with eyes open</td>
<td>Lateral sway S.D.</td>
<td>°</td>
<td>0.86 (0.78-1.07)**</td>
<td>0.83 (0.7-0.96)*</td>
<td>0.79 (0.76-0.84)</td>
<td>0.91</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Antero-posterior sway S.D.</td>
<td>°</td>
<td>1.06 (0.91-1.32)**</td>
<td>1.1 (0.92-1.29)**</td>
<td>0.87 (0.81-0.94)</td>
<td>1.06</td>
<td>53</td>
</tr>
<tr>
<td>Standing balance with eyes closed</td>
<td>Lateral sway S.D.</td>
<td>°</td>
<td>0.85 (0.79-0.96)</td>
<td>0.88 (0.81-1.07)**</td>
<td>0.84 (0.79-0.89)</td>
<td>1.11</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Antero-posterior sway S.D.</td>
<td>°</td>
<td>1.12 (0.98-1.41)**</td>
<td>1.28 (1.09-1.55)**</td>
<td>0.94 (0.86-1.03)</td>
<td>1.23</td>
<td>41</td>
</tr>
<tr>
<td>Turning balance (360°)</td>
<td>Duration</td>
<td>s</td>
<td>7.1 (5.67-9.82)**</td>
<td>10.7 (7.16-15.2)**</td>
<td>3.5 (2.64-4.78)</td>
<td>7.15</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Number of steps</td>
<td>s</td>
<td>5.61 (4.36-7.64)**</td>
<td>7.21 (4.88-12.1)**</td>
<td>2.29 (1.28-3.01)</td>
<td>4.16</td>
<td>80</td>
</tr>
<tr>
<td>Sitting down</td>
<td>Forward inclination duration</td>
<td>s</td>
<td>3.02 (2.42-5.01)**</td>
<td>4.42 (2.74-6.68)**</td>
<td>1.7 (1.32-2.44)</td>
<td>3.77</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Straightening duration</td>
<td>s</td>
<td>1.66 (1.18-2.57)**</td>
<td>2.76 (1.57-3.68)**</td>
<td>1.08 (0.68-1.58)</td>
<td>2.36</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Overall duration</td>
<td>s</td>
<td>5.14 (3.93-7.55)**</td>
<td>8.05 (5.75-9.7)**</td>
<td>3.14 (2.42-4.18)</td>
<td>5.49</td>
<td>60</td>
</tr>
<tr>
<td>Mean fwd inclination velocity</td>
<td>°/s</td>
<td>11.6 (6.45-15.5)**</td>
<td>7.28 (5.1-11.4)**</td>
<td>24.9 (16.1-34.4)</td>
<td>8</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Mean straightening velocity</td>
<td>°/s</td>
<td>20.2 (13.8-26.7)**</td>
<td>12.8 (7.56-22.2)**</td>
<td>35.3 (22.8-54.3)</td>
<td>15</td>
<td>43</td>
<td></td>
</tr>
</tbody>
</table>

The significance level (if any) of the difference between parameter distributions in patients’ and control samples (Wilcoxon test) is indicated by * (p=0.005) or ** (p=0.0001).

of the various parameters in the different decades suggested that performance did not change significantly as a function of age. In fact, analysis of variance was unable, in any parameter, to show statistically significant differences between the various decades (F = 0.97, p = 0.42). This result was confirmed by a comparison between the medians carried out using the non-parametric Kruskal-Wallis test (p = 0.47).

Based on this result, it was deemed reasonable to conclude that, in this sample of healthy people, performance as measured by the parameters here considered was independent of age and, therefore, that all the subjects in the control sample could be gathered in one homogeneous sample against which to compare the performance of the patients. Thus, the parameter median, interquartile intervals, and either 95th or 5th percentile (see above), were calculated for the whole control sample (Table I).

The medians and interquartile intervals of the two patient samples were then compared (Table II). Comparison of these two samples was not one of our aims and was, in any case, prevented by the fact that they were not homogeneously composed (see Materials and Methods section). Instead the statistical parameters describing each patient sample were compared to the corresponding parameters in the control sample (Table I). The non-parametric Wilcoxon test showed that sixteen out of twenty items in sample A and fourteen in sample B showed a difference at the level of p = 0.0001 versus the results in the controls, and one item in sample A and two in sample B showed a difference at the level of p = 0.005. The four items in each sample that did not differ significantly from the controls (p ranging from 0.13 to 0.51) were all related to stance (Table I).

When statistically significant differences were observed, the distributions of parameter values in the different samples were well separated from each other. This was particularly evident for the parameters relating to the "arising from chair" and "turning balance (360°)" manoeuvres. Two good examples are given in Fig. 2-A (overall movement duration when arising from chair) and 2-B (number of steps when turning on the spot), in which the percentages are reported on the abscissa and the corresponding parameter values in the three samples on the ordinates. In these diagrams, the distributions of the values in the control sample are plotted by decade of age, to provide visual confirmation that they are substantially independent of age.

Finally, for each parameter the percentage of subjects in samples A and B who had a worse performance than those fixed as normality thresholds (i.e., above the 95th or below the 5th percentile depending on the parameter) was evaluated. These percentages will be referred to as "rejection ratios" (RRs). They are given in the last column of Table I. Their values ranged from 10% (Immedi-ate standing, lateral sway S.D.) to 80% (Turning balance number of steps, most being around 50% (namely: six values out of twenty lower than 40%, eleven between 40% and 60%, three greater than 60%).

**Discussion**

Even though the movements of the Tinetti test are only a subset of the possible movements of daily life and the test is conducted in a setting that does not reproduce the patient's habitual environment, Tinetti test results are considered valuable in assessing a subject's motor ability (13.14). Since the ESTT reproduces a significant subset of this test, supplementing it only with instrumental measurements, it is likely to provide the same qualitative information as the Tinetti test manoeuvres it takes into account, while also allowing objective quantification.

The measurements produced by the ESTT are objective in that i) they are not influenced by factors such as the observer's experience, impartiality, expectation, tendency to minimise or emphasise particular aspects of the movement, and so on; ii) the measurement system causes no discomfort to the subject, does not disturb him/her during the test, is self-calibrating and thus insensitive to minor positioning inaccuracy; iii) signal analysis and parameter calculation are carried out automatically by the PC which guarantees reproducibility and objectivity. Moreover, in principle the ESTT is not subject to floor-ceiling effects, and allows finer grading of the score thanks to the resolution of the measuring device and signal processing procedures. In short, it meets international measurement standards criteria.

The working hypothesis of the present study was that instrumental measurement should improve the capacity of the conventional Tinetti scale to describe and measure possible impairment of equilibrium control. In particular, some of the adopted parameters could be helpful in this respect, and the measurements obtained from the patient, compared with normal performance, should provide indications as to the degree of alteration. Indeed, the results reported here lead to the conclusion that the performance of the tested subjects is probably scarcely dependent on age, but instead more influenced by factors associated with co-morbidity. As far as the RR values are concerned, some parameters did show quite a good power of discrimination between normal and abnormal behaviours, these latter perhaps being at risk behaviours. The duration of the rising movement during sit-to-stand and the number of steps taken when turning on the spot seem to be two such parameters, whereas those describing the subject's stance seem to be less sensitive. We do not yet know what the exact relationship is between pathology and the measured values. Previous studies available in the literature are of no great help on this point.

A follow-up study has recently been started in the same geriatric units participating in the present study in order to study and assess the sensitivity of the considered parameters in predicting the risk of fall in the elderly and their correlation with possible risk factors. It consists of:

i) defining the initial status of each patient in terms of values of his/her ESTT parameters;
ii) correlating the evolution of ESTT parameter values with the number of falls (if any) during the follow up, in order
iii) to assess the ability of the ESTT to distinguish normal from abnormal behaviour;
iv) to assess the prognostic value of each ESTT parameter or set of parameters.

v) to derive a quantitative model, based on ESTT para-
meters and predicting the possibility of that patient having a fall within a given time. The said study might provide a model for the assessment of the usefulness of the Tinetti test and the ESTT itself in other applications. Indeed, besides the prediction of the risk of fall, the ESTT could be useful and provide objective measurements for studying other pathologies of interest in neurology, such as Parkinson’s disease (6) or acute stroke (7), for verifying and monitoring rehabilitation treatments, and for measuring different Tinetti test manoeuvres (such as those related to gait assessment)from the ones considered here. Eventually, it might be a helpful objective instrument for the assessment of the Tinetti test itself in different contexts.

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References