Estimating Disability in Patients with Essential Tremor: Comparison of Tremor Rating Scale, Spiral Drawing, and Accelerometric Tremor Power

Petr Hollý, MD,1 Tereza Hubená, MEng,2 Martin Čihák, MSc,1 Aneta Pavlíková, BSc,2 David Kemlink, MD, PhD,1 Olga Ulmanová, MD, PhD,1 Jan Rusz, MEng, PhD,1,3 Robert Jech, MD, PhD,1,4 Radim Krupička, MEng, PhD,1,4 and Evžen Ružička, MD, DSc1,5,∗

Abstract: Background: Although performance rating scales, spiral drawing, water pouring, and accelerometry are commonly used to assess tremor severity, the extent to which their results correlate with impairment in activities of daily living (ADL) remains unclear.

Objective: The aim was to identify the most effective predictors of ADL in essential tremor (ET).

Methods: Forty ET patients were examined using The Essential Tremor Rating Assessment Scale (TETRAS), spiral drawing, volume of water spilled, and accelerometric tremor power. Root-mean-square error, R², and F-test were calculated for models predicting TETRAS ADL subscore.

Results: TETRAS Performance Subscale explained the variability in TETRAS ADL with an R² value of 0.686. Models incorporating spiral rating and accelerometric tremor power (R² = 0.731) and water spillage volume (R² = 0.756) were not statistically superior.

Conclusions: TETRAS performance subscore predicted nearly 70% ADL impairment in ET patients. Incorporating the spiral rating, accelerometric tremor power, and water pouring test did not enhance ADL estimation.

Essential tremor (ET) is the most common movement disorder in adults.1 In practice, clinical scales such as the Fahn–Tolosa–Marin Tremor Rating Scale2 or The Essential Tremor Rating Assessment Scale3 (TETRAS) have been standardized to evaluate ET severity and functional impact. However, the assessment depends on the raters’ experience and subjective judgments expressed on ordinal scales, thus not providing an objective linear quantification of tremor severity.1–6 Drawing a spiral is a method commonly used to quickly assess the severity of tremor in the clinic, with the advantage of easy repeatability and the possibility of tracking the evolution of disability over time. However, quantifying tremor severity based on the spiral drawing relies on the experience and subjective judgment of the examiner.7,8 Another method of estimating functional impairment caused by tremor is to measure the volume of water spilled when pouring from cup to cup.2 Its contribution to disability assessment has only been sporadically investigated.9 Technology-based methods such as quantifying tremor at drawing on a graphics tablet provide high accuracy but have not been widely adopted in clinical practice.10–12 More recently, wearable devices containing accelerometers have emerged to capture real-time data and determine tremor characteristics such as amplitude and frequency, body distribution, and coherence, providing accurate measurement of tremor severity and variability.6,13,14 The aim of this study was to determine how clinical measures of tremor (the ET rating scale, spiral drawing, and the water pouring test) contribute to estimating the

[1]Department of Neurology and Center of Clinical Neuroscience, Charles University, First Faculty of Medicine and General University Hospital in Prague, Prague, Czech Republic; [2]Department of Biomedical Informatics, Faculty of Biomedical Engineering, Czech Technical University in Prague, Prague, Czech Republic; [3]Department of Circuit Theory, Faculty of Electrical Engineering, Czech Technical University in Prague, Prague, Czech Republic.

*Correspondence to: Prof. Evžen Ružička, Department of Neurology and Center of Clinical Neuroscience, Charles University, First Faculty of Medicine and General University Hospital in Prague, Kralovske Vinohrady 6, 140 00 Prague, Czech Republic; E-mail: eruzi@ff1.cuni.cz

Keywords: Essential tremor, accelerometry, TETRAS, activities of daily living, spiral drawing, water pouring.

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severity of disability as reflected in the activities of daily living (ADL). Additionally, the study aimed to assess if accelerometric measurement of tremor power could refine this estimation.

Patients and Methods

Forty patients with ET (22 women and 18 men, mean age: 66.8 ± 14.4 years) were recruited at the Movement Disorder Center of the Department of Neurology, General University Hospital in Prague. The study was approved by the institutional ethics committee; all participants were properly informed and signed the informed consent.

Every participant was examined by a trained neurologist (P.H.), using TETRAS including the ADL and Performance Subscale (PS). The composite score of upper limb (UL) action tremor (TETRAS PS item 4) was calculated by summing the subscores of the right and left UL postural tremor in forward outstretched and lateral wing-beating UL position, and kinetic tremor during finger-to-nose test. Each patient was asked to draw a spiral with a pen on paper in an empty 12 × 12-cm square box, starting from a central dot, first with the dominant hand and then the nondominant hand, without resting the elbow on the table. The spirals were later blindly evaluated by 2 movement disorder specialists (E.R. and O.U.) according to the Bain and Findley 10 degree scale (BF rating scale). The ratings by the 2 raters were strongly correlated, differing by a maximum of 1 point for both the dominant hand (Kendall’s τ = 0.89, 95% confidence interval [CI] = [0.83; 0.94]) and the nondominant hand (Kendall’s τ = 0.88, 95% CI = [0.82; 0.93]). Due to the high level of agreement, the mean scores of both raters were used in further calculations. Next, the patient was asked to pour 250 mL of water from 1 measuring cup to another (thrice back and forth). The volume of water spilled was calculated as the difference in the contents of the measuring cup before and after pouring.

UL tremor was assessed using triaxial accelerometers (MTw Awinda, Xsens, the Netherlands) fixed to the back of the patient’s hand. Tremor was recorded in sitting position with arms outstretched, in the wing position, and during targeted finger-to-nose movements. Power of tremor was calculated as the maximum of power spectrum using Welch’s power spectral density estimation. Dominant frequency values ranged between 2 and 12 Hz. Tremor power was log transformed with base 10 and subsequently scaled by a factor of 10 in all analyses.

We constructed 3 linear regression models, all with TETRAS ADL as the outcome variable. Model 1 (M1) included TETRAS PS as the only predictor. In model 2 (M2), our aim was to include a measure of UL tremor and a spiral drawing score. As we utilized 2 measures of UL tremor (standardized clinical scoring according to TETRAS PS item 4 and the accelerometric tremor power) and 2 spiral drawing rating systems (TETRAS PS item 6 and the BF scale), we first needed to determine which measures explain most of TETRAS ADL variance and thus should be entered into the M2 model. To do so, we developed 4 linear regression models (Ma–Md) with TETRAS ADL as the outcome and individual measures as predictors (Ma, TETRAS PS 4; Mb, accelerometric tremor power; Mc, TETRAS PS 6; and Md, BF scale). Finally, in model 3 (M3), we combined the selected predictors from M2 with the volume of spilled water. In each model, all predictor variables were entered simultaneously. The root-mean-square error (RMSE) and R^2 were computed to assess which of the 3 models (M1, M2, and M3) provided the most reliable predictions of ADL. RMSE estimates how large the difference will be between the predicted and the real values of the dependent variable. In other terms, we investigated whether TETRAS PS total score is superior to the individual measures of UL tremor and the spiral drawing, and if the inclusion of the volume of spilled water improves the estimations. All analyses were conducted using R software, with statistical significance set at α = 0.05.

Results

Descriptive statistics are presented in Table 1, and the correlation matrix of variables is presented in Table S1. All summary scores had very good internal consistency (Cronbach’s α ≥ 0.89, McDonald’s ω ≥ 0.89). No variable differed between the dominant and the nondominant UL (Table 1). In the following analyses, we therefore used the average values calculated from both UL.

In the water pouring test, the median volume of water spilled was 5 mL (interquartile range: 0–30 mL). Fourteen patients (35%) did not spill any water, whereas 3 patients (7.5%) spilled the entire volume. Figure S2 shows the distribution of variables, including the spilled water volume, TETRAS PS total subscore, values of TETRAS PS items 4 and 6, BF spiral ratings, and accelerometric tremor power.

Coefficient estimates, R^2, and RMSE for each model are presented in Table 2, and variance inflation factors and partial and semipartial correlations are presented in Table S2. No significant difference was found between the RMSE or R^2 of Ma and Mb, or between that of Mc and Md (see Table 2), suggesting that accelerometric assessment of tremor power does not explain less variance in TETRAS ADL compared to clinical assessment according to TETRAS PS 4, nor does the spiral drawing task assessed using the BF scale explain less variance in TETRAS ADL compared to TETRAS PS 6. Therefore, accelerometric tremor power and BF spiral drawing score could be chosen as predictors in M2. When comparing the performance of M1 with that of M2 and M3, neither M2 nor M3 showed better R^2 or RMSE compared to M1 (based on 95% CIs; see Table 2 and Fig. S1). Additionally, M3 did not outperform M2 in terms of R^2 and RMSE (based on 95% CIs; see Table 2) or in terms of explained variance ($F_{,[3,16]} = 3.74, \, P = 0.061$).

Discussion

A number of clinical examination scales and tests are used to assess the severity of tremor. However, clinical scales depend...
on the patient’s subjective perception or the examiner’s judgment, are usually based on ordinal grading, and thus do not provide a linear relationship between the scale scores and tremor amplitudes, despite the proven internal consistency and validity of the scales.\textsuperscript{4,17} Therefore, various instrumental methods measuring neurophysiological or physical properties of the oscillations have been proposed.\textsuperscript{18,19} Accelerometric measurement of tremor is an attractive addition because of its relative simplicity, accurate frequency capture, and calculation of tremor amplitude.\textsuperscript{6,20,21} However, in routine clinical practice, instrumental measurements are

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>P (dominant vs. nondominant UL)</th>
<th>α</th>
<th>ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADL score</td>
<td>19</td>
<td>10</td>
<td>0.91</td>
<td>0.93</td>
<td></td>
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<tr>
<td>TETRAS PS score</td>
<td>13.3</td>
<td>6.6</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>TETRAS PS 4 (both UL summary score)</td>
<td>9.5</td>
<td>3.6</td>
<td>0.94</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>TETRAS PS 6</td>
<td>2.2</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>BF spiral score (both UL)</td>
<td>4.6</td>
<td>2.2</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Spilled water (mL)</td>
<td>41</td>
<td>74</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Mean tremor power (10 × log((m/s(^2))/Hz))</td>
<td>−13</td>
<td>10</td>
<td>0.94</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>TETRAS PS 4 (dominant UL)</td>
<td>4.6</td>
<td>2.1</td>
<td>0.08</td>
<td>0.90</td>
<td>0.91</td>
</tr>
<tr>
<td>TETRAS PS 4 (nondominant UL)</td>
<td>4.9</td>
<td>1.6</td>
<td>0.89</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>BF spiral score (dominant UL)</td>
<td>4.5</td>
<td>2.5</td>
<td>0.19</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>BF spiral score (nondominant UL)</td>
<td>4.8</td>
<td>2.2</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Mean tremor power (dominant UL) (10 × log((m/s(^2))/Hz))</td>
<td>−13</td>
<td>12</td>
<td>0.15</td>
<td>0.89</td>
<td>0.89</td>
</tr>
<tr>
<td>Mean tremor power (nondominant UL) (10 × log((m/s(^2))/Hz))</td>
<td>−14</td>
<td>10</td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>

\(P\)-values were computed using 2-sided paired Welch’s \(t\)-test. Abbreviations: SD, standard deviation; UL, upper limb(s); \(\alpha\), Cronbach’s alpha; \(\omega\), McDonald’s omega; ADL, activities of daily living; TETRAS PS, The Essential Tremor Rating Assessment Scale Performance Subscale score; TETRAS PS 4, summary score of UL tremor; TETRAS PS 6, spiral drawing score; BF, Bain and Findley rating scale; NA, not applicable.

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Intercept</th>
<th>Coefficient(s)</th>
<th>(R^2) [95% CI]</th>
<th>RMSE [95% CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model M1</td>
<td>1.9</td>
<td>0.686 [0.524; 0.812]</td>
<td>5.53 [4.57; 6.83]</td>
<td></td>
</tr>
<tr>
<td>TETRAS PS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multivariate model M2</td>
<td>11.5</td>
<td>0.731 [0.524; 0.839]</td>
<td>5.11 [4.35; 6.61]</td>
<td></td>
</tr>
<tr>
<td>Tremor power (10 × log((m/s(^2))/Hz))</td>
<td></td>
<td>0.3*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF spiral score</td>
<td></td>
<td>2.5*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multivariate model M3</td>
<td>11.6</td>
<td>0.756 [0.581; 0.854]</td>
<td>4.87 [4.13; 6.21]</td>
<td></td>
</tr>
<tr>
<td>tremor power (10 × log((m/s(^2))/Hz))</td>
<td></td>
<td>0.3*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF spiral score</td>
<td></td>
<td>2.0*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spilled water (mL)</td>
<td></td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Ma (BF spiral score)</td>
<td>1.6</td>
<td>3.7*</td>
<td>0.675 [0.483; 0.802]</td>
<td>5.62 [4.76; 6.82]</td>
</tr>
<tr>
<td>Model Mb (TETRAS PS 6—spiral score)</td>
<td>1.4</td>
<td>7.7*</td>
<td>0.600 [0.493; 0.796]</td>
<td>6.24 [4.81; 6.90]</td>
</tr>
<tr>
<td>Model Mc (tremor power)</td>
<td>28.4*</td>
<td>0.7*</td>
<td>0.592 [0.356; 0.763]</td>
<td>6.30 [5.15; 8.45]</td>
</tr>
<tr>
<td>Model Md (TETRAS PS 4—UL tremor)</td>
<td>−1.8</td>
<td>2.2*</td>
<td>0.588 [0.301; 0.756]</td>
<td>6.33 [5.24; 9.42]</td>
</tr>
</tbody>
</table>

Models with TETRAS ADL as an outcome.
\(*P < 0.05.\)

Abbreviations: CI, confidence interval; RMSE, root mean square error; TETRAS PS, The Essential Tremor Rating Assessment Scale Performance Subscale score; BF, Bain and Findley rating scale; TETRAS PS 6, spiral drawing score; TETRAS PS 4, summary score of UL tremor; UL, upper limb(s); ADL, activities of daily living.
Both the 10-grade BF spirography scale measurement of tremor power adequately predicted ADL involvement-predictor of ADL impairment in patients with ET. The 10-grade pouring may be feasible anymore.

Severe tremors, neither the spiral drawing nor the water pouring were readily transferable to patients with more severe impairment. However, it should be taken into account that for the most limited use, accelerometers remain useful research tools for accurately quantifying tremor. Moreover, the random variability within the test and retest for tremor mitigates the benefits of the greater accuracy and precision provided by the sensors. Therefore, the water pouring test appeared to be of limited use, accelerometers remain useful research tools for accurately quantifying tremor. However, the validity of the measurements depends on the type of task and the anatomical localization of the tremor. Moreover, the random variability within the test and retest for tremor mitigates the benefits of the greater accuracy and precision provided by the sensors. Therefore, the water pouring test appeared to be of limited use, accelerometers remain useful research tools for accurately quantifying tremor.

In conclusion, TETRAS PS appears to be a robust overall predictor of ADL impairment in patients with ET. The 10-grade spiral rating according to the BF rating scale and the accelerometric measurement of tremor power adequately predicted ADL involvement but did not outperform TETRAS PS.

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Disclosures

Ethical Compliance Statement: An institutional ethics committee of the General University Hospital in Prague approved the study. All patients declared their consent in writing. We confirm that we have read the journal’s position on issues involved in ethical publication and affirm that this work is consistent with those guidelines.

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Financial Disclosures for the Previous 12 Months: The authors declare that there are no additional disclosures to report.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References


Supporting Information

Supporting information may be found in the online version of this article.

Table S1. Correlation matrix of variables.

Table S2. Variance inflation factors and partial correlations of the predictors with the outcomes.

Figure S1. Mean square errors of models with the ADL (activities of daily living) score as an outcome. Vertical bars represent 95% adjusted percentile bootstrapped confidence intervals of the respective means. M1: model with TETRAS PS (The Essential Tremor Rating Assessment Scale Performance Subscale) score as a predictor. M2: multivariate model with the Bain and Findley spiral drawing score, and the accelerometric tremor power as predictors. M3: multivariate model with the mean spiral drawing score, mean tremor power, and volume of spilled water as predictors. *Significant difference based on 95% confidence interval.

Figure S2. Distribution of variables. The dots represent individual patient values, and the box plots show the distribution of each variable on its scale. Tremor power is expressed as $10 \times \log ((\text{m/s}^2)^2/\text{Hz})$, and the volume of spilled water is given in milliliters. BF, Bain and Findley rating scale; TETRAS PS, The Essential Tremor Rating Assessment Scale Performance Subscale score; TETRAS PS 4, summary score of UL (upper limb) tremor; TETRAS PS 6, spiral drawing score.