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Windowed FFT – a time-variant spectral analysis: applicability during the head-up tilt test

T. Szili-Török¹, Z. Gingl², A. Kardos³, L. Halmai¹, L. Rudas¹

The spectral assessment of heart rate variability (HRV) and blood pressure variability (BPV) is a well-established method for the identification of rhythmic fluctuations during stationary conditions, but there is no generally accepted method of describing dynamic changes in such spectral patterns. Our goal was to introduce an alternative means of assessing the dynamics of spectral HRV.

Continuous ECG and non-invasive BP recordings on 29 subjects during head-up tilt testing were subjected to analysis. The total spectral power and the power over the low (LF: 0.04–0.15 Hz) and the high-frequency (HF: 0.15–0.4 Hz) spectral bands were recalculated in an overlapping series with constant time shifting of the initial data-point.

The time course of LFHRV augmentation, with an early peak and subsequent levelling within the first 2 of tilting, was also documented, with parallel changes in LFBPV (LFHRV ms²/Hz: 290 ± 96 supine, 2707 ± 1557 maximum after tilt, p < 0.05 LFBPV mmHg²/Hz: 10 ± 4 supine, 58 ± 26 maximum after tilt, p < 0.05). In a subgroup of 7 patients who exhibited syncope upon tilting, a statistically significant early increase HFHRV was also detected, followed by significant decline by the second minute of tilting (HFHRV ms²/Hz: 143 ± 80 supine, 1054 ± 902 maximum after tilt, 125 ± 84 minimum after tilt). This early HFHRV peak was absent in the group of tilt-negative subjects. Another characteristic feature of the tilt positive group was a second phase of LFBPV and LFHRV elevation preceding the syncope episode.

Windowed fast Fourier transformation is a suitable method for assessment of dynamic HR and BP spectral changes during upright tilt testing. The method is well applicable for the analysis of tilting-induced autonomic responses. *J Clin Basic Cardiol 1999; 2: 241–4.*

**Key words:** spectral analysis, heart rate variability head up tilt

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**Methods**

**Patient population**

Records on 29 patients during HUT were selected from our data base. All subjects had been referred to the arrhythmia service because of unexplained syncope. During the initial assessment, including history, physical examination, ECG and echocardiography, a cardiac cause of the syncope was definitely excluded in each case. Only virtually noise-free records were considered for further analysis. Records with ectopic beats were also excluded from the study.

**Head-up tilt test**

The tilt-table test was performed in a quiet room with low light and always between 10 and 12 a.m. After 30 min in a supine resting position, patients were tilted to 70° for 40 min. A table with a footboard support was utilised, and the tilt position was reached in 30 s. Baseline ECG and BP recordings were made for 10 min prior to tilting, and were continued throughout the study. Syncope was defined as a transient loss of consciousness, accompanied by a loss of postural tone. Warning symptoms of syncope include nausea, vomiting, impaired vision, the hearing of distant sounds, a slow response to verbal commands, and a partial loss of postural tone. Dizziness accompanied by one or more of the above symptoms was defined as presyncope.

**Data acquisition and analysis**

BP was monitored with a photoplethysmograph (Finapres 2300, Ohmeda). ECG signals were recorded by a 5-lead system. The BP and ECG signals were transmitted through an amplifier, filter and analogue-digital converter into an IBM-AT-compatible computer. Data were stored and analysed off-line by means of a program developed in our laboratory. With our system the precision of RR interval detection is 2 ms, and that of BP detection is 1 mmHg. Power spectrum analysis was performed on 2-min segments of the ECG and BP records by using FFT over two frequency bands. The low-frequency band (LF) of the HRV and systolic BPV was defined at 0.04–0.15 Hz, and the high-frequency component (HF) at 0.15–0.4 Hz [4].
Winowed FFT
Winowed FFT is a narrow time Fourier transformation. Briefly, the method is based on recalculation of the FFT with a variable shifting of the initial complexes in time, allowing the generation of 3D representations of spectral changes. The principles of the mathematical assessment were formulated by Gábor in 1946 [5]; the corresponding equation is:

\[ X(f, \tau) = \int_{-\infty}^{\infty} w(t, \tau) x(t)e^{-i2\pi ft} dt \]

where \( x(t) \) is the signal to be transformed, \( w(t, \tau) \) is the window function, \( \tau \) is the time variable for the time-dependent spectrum \( X(f, \tau) \).

For \( w(t) \), the Hamming window is used with 2-min durations. FFT was performed to calculate the power spectrum for all frequencies for this time range. Shifting the window in time yields the time-dependent power spectrum. In this study, the method was applied for both the RR interval and BP records. The time course of HR and systolic BP spectral changes was analysed in each case, and power spectrum values of certain characteristic tilt stages were determined. Values calculated from the last sequence prior to tilting were defined as baseline. Post-tilt maximum and minimum values in the LF and HF power bands for both HR and systolic BP were determined and compared with the baseline. For those exhibiting syncope, the corresponding values were also determined at the time of fainting.

Statistical analysis
Changes were compared with the baseline using ANOVA for repeated measures. For parameters exhibiting a non-Gaussian distribution, the Friedman one-way repeated measures ANOVA on ranks was used. The level of statistical significance was set at \( p < 0.05 \).

Results
Twenty-two subjects exhibited no abnormal reactions during the tilt test (tilt-negative cases). Syncope developed in 7 subjects (tilt-positive cases), 7 to 30 min after tilting. The tilt-positive subjects displayed a “mixed response”, characterised by bradycardia and a variable degree of hypotension. Demographic data on the tilt-positive subjects are shown in Table 1. The mean ages of the tilt-positive and negative subjects were similar (22.1 ± 4.4 and 23.5 ± 3.7 years, respectively; \( p = \text{NS} \)). Upon tilting, there were immediate fluctuations in HR and systolic BP power spectral components (Figures 1 and 2). A statistically significant increase in the total-frequency systolic BPV (TFBPV) within 2 min from the beginning of the manoeuvre was mainly due to an LFBP in both groups (Tables 2 and 3). Subsequently, TFBPV and LFBP decreased in both groups and levelled at lower-than-maximum values for several minutes. Nevertheless, the minimum TFBPV and LFBP values after tilting in this phase remained significantly higher than the baseline in the tilt-negative group (Table 2). The same tendency was seen in the tilt-positive group, but the difference in minimum TFBPV and LFBP did not reach statistical significance as compared with the baseline (Table 3). TFFH and LFHFR increased significantly in response to tilting, and then declined quickly to post-tilt minimum values, but these were still significantly higher than the baseline in both groups. Peaking occurred within the first minute after the completion of tilting. A different response was seen when HHFRV was assessed. In the tilt-negative group, HHFRV decreased immediately on tilting and underwent no subsequent changes, whereas a significant increase in this parameter was seen in the tilt-positive group. This increase reached its peak within 60 s after tilting, and HHFRV then quickly returned to a lower-than-baseline level (Table 3). The syncopal episode itself in the tilt-positive group was characterised by a diminution of all HRV spectral bands, though this decline reached statistical significance for only the TFFH and LFHFR bands as compared with the baseline. There was a similarly marked reduction in the TFBPV and LFBP components in association with syncope. In contrast, the HFBP component displayed a small and statistically non-significant increase (Table 3).

Table 1. Demographic and tilt-table test data on patients with positive tilt-table test

<table>
<thead>
<tr>
<th>Pt. no.</th>
<th>Age (yr)</th>
<th>Gender</th>
<th>Time of syncope from tilting (min)</th>
<th>dSBP (mmHg)</th>
<th>dHR (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>F</td>
<td>8</td>
<td>135</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>F</td>
<td>7</td>
<td>50</td>
<td>59</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>M</td>
<td>10</td>
<td>72</td>
<td>39</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>M</td>
<td>8</td>
<td>95</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>F</td>
<td>10</td>
<td>47</td>
<td>43</td>
</tr>
<tr>
<td>6</td>
<td>23</td>
<td>F</td>
<td>6</td>
<td>62</td>
<td>41</td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>F</td>
<td>30</td>
<td>68</td>
<td>52</td>
</tr>
</tbody>
</table>
Discussion

The assessment of HRV by spectral analysis is gaining increasing use in clinical cardiology [1, 2]. However, the method of spectral analysis dissect the series of events into discrete sequences, allowing no overlap in the assessment. Only a few publications related to time-dependent spectral assessment [3, 6], but the methods proposed are not yet widely accepted. Thus, spectral analysis currently remains the best possibility for the description of stationary states. Dynamic changes are usually expressed as differences between two stable conditions, without any analysis of the process of transition between the two states. The effect of upright tilting on HRV is typically characterised by comparing the supine resting condition with that in a given post-tilt period. This post-tilt transient is defined either in a given time interval after the beginning of or prior to termination of the tilt manoeuvre [7–9], or at a fixed time preceding the syncopal event [10]. Our results indicate complex fluctuations in the HRV and BPV spectral parameters upon tilting. The major finding in this study is that LFHRV and LFBPV increase markedly and promptly after the tilt position is reached. If FFT is used this effect can not be observed, because it occurs in the first 30 s of the post-tilt period. At the time of presyncope, when the sympathetic tone is declining, these components are greatly decreased. Stationary analysis would yield a quite different spectrum in an early assessment starting with the tilt procedure, as compared with a delayed analysis performed even only 2 min post-tilting. Our observations suggest that certain discrepancies in the literature tilt test results might have been due to the different timings of the assessment. Theodorakis et al. generated a series of adjoining spectral segments to characterise the tilt-induced responses [11], and presented first documented time-dependent spectral fluctuations. Pagani et al. selected “stationary sections of data both at rest and during tilting” for assessment; the exact timing of their post-tilt data acquisition, however, was not reported [12]. Montano et al. reported on a study in which they applied different extents of angle tilting for periods of 10 min. From the continuous recordings, stationary segments devoid of arrhythmia [200 to 500 RR intervals] were analysed, but the timing of data acquisition in relation to the onset of tilting was not stated [13]. Boulos et al. determined spectral changes by comparing the baseline values with those for the last 256 consecutive beats of a 15-min tilt test [9]. Bootsma et al. reported on the effects of different angle tilting, but they excluded from their analysis the first minute of recordings in each position: min 2 to 5 were used for computation of HRV spectra [7]. Mizumaki et al. established tilt-induced spectral responses by comparing supine resting values with those recorded during the last 200 beats until 1 min before the end of the tilt [10]. Bloomfield et al. performed comparisons between data acquired in a supine position and those recorded during the last 5 min of a 13-min tilting [8]. In general, the investigators tended to select artefact-free stationary segments of the recordings, thereby precluding assessment of the phase of the postural change itself. Most of the cited reports indicated a transient stabilisation post-tilting, followed by a marked decrease in the spectral components preceding the syncopal episode.

Table 3. Changes in spectral components during head-up tilt test in the tilt-positive group (n = 7)

<table>
<thead>
<tr>
<th></th>
<th>Supine position</th>
<th>Maximum after tilt</th>
<th>Minimum after tilt</th>
<th>During syncope</th>
</tr>
</thead>
<tbody>
<tr>
<td>THFHR (ms²/Hz)</td>
<td>673±202</td>
<td>4379±2064*</td>
<td>1072±670*</td>
<td>243±105*</td>
</tr>
<tr>
<td>LFHRV (ms²/Hz)</td>
<td>290±96</td>
<td>2707±1557*</td>
<td>663±394*</td>
<td>92±31*</td>
</tr>
<tr>
<td>HFBHR (ms²/Hz)</td>
<td>143±80</td>
<td>1054±902*</td>
<td>125±84NS</td>
<td>38±28NS</td>
</tr>
<tr>
<td>TFBPV (mmHg²/Hz)</td>
<td>24±9</td>
<td>86±33*</td>
<td>37±21NS</td>
<td>17±6*</td>
</tr>
<tr>
<td>LFBPV (mmHg²/Hz)</td>
<td>10±4</td>
<td>58±26*</td>
<td>23±14NS</td>
<td>2±0*</td>
</tr>
</tbody>
</table>

* p < 0.05 vs. supine position, NS non-significant

Table 2. Changes in spectral components during head-up tilt test in the tilt-negative group (n = 22)

<table>
<thead>
<tr>
<th></th>
<th>Supine position</th>
<th>Maximum after tilt</th>
<th>Minimum after tilt</th>
<th>During syncope</th>
</tr>
</thead>
<tbody>
<tr>
<td>THFHR (ms²/Hz)</td>
<td>1255±392</td>
<td>3835±1892*</td>
<td>1618±415*</td>
<td></td>
</tr>
<tr>
<td>LFHRV (ms²/Hz)</td>
<td>514±163</td>
<td>2300±977*</td>
<td>888±223*</td>
<td></td>
</tr>
<tr>
<td>HFBHR (ms²/Hz)</td>
<td>557±234</td>
<td>289±94NS</td>
<td>247±97NS</td>
<td></td>
</tr>
<tr>
<td>TFBPV (mmHg²/Hz)</td>
<td>12±3</td>
<td>110±28*</td>
<td>38±10*</td>
<td></td>
</tr>
<tr>
<td>LFBPV (mmHg²/Hz)</td>
<td>1±0</td>
<td>54±11*</td>
<td>22±5*</td>
<td></td>
</tr>
<tr>
<td>HFBPV (mmHg²/Hz)</td>
<td>1±0</td>
<td>4±1NS</td>
<td>2±0NS</td>
<td></td>
</tr>
</tbody>
</table>

* p < 0.05 vs. supine position, NS non-significant

THFHR: total-frequency heart rate variability, LFHRV: low-frequency heart rate variability, HFBHR: high-frequency heart rate variability, TFBPV: total-frequency blood pressure variability, LFBPV: low-frequency blood pressure variability, HFBPV: high-frequency blood pressure variability.
positive subjects prior to syncope (Figures 2 and 3). However, phase of LFHRV and HFHRV elevation was seen among tilt-tral constellation among negative subjects remained unchanged demands further studies. During the phase of equilibrium, previously . The significance of this finding is not clear and 11], but no early post-tilt peak of HFHRV has been reported an increased HFHRV just prior to an episode of syncope [9, 14]. Nevertheless, the subsequent equilibrium, which is basically maintained until the end of tilting in tilt-negative subjects, is still characterised by a predominance of LFHRV markers. The continuous assessment allowed us to detect a short-lasting increase in HFHRV among tilt-positive subjects very early after tilting. This temporary increment in HFHRV among syncope subjects is strikingly different from the im-

References

2. Kvennawaj-Arts CMA, Kolle LAA, Hopman JCR, Snoeckens GB, van Geijn
6. Kuo TB, Chn SHH. Continuous, on-line, real-time spectral analysis of sys-

Figure 3. 3D projection of the HRV (upper panel) and BPV (lower panel) spectral changes following the upright tilt as assessed by windowed FFT in the same syncopal patients as in Fig. 2. The spatial projection allows a thorough assessment of the temporal changes and interrelationship of all spectral components. Thus, it is apparent that the double elevation in the LFBPV response depicted in Fig. 2 is related to changes in different segments of the LF band. Even the two minor elevations in the HFBPV band are quite discernible.
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