Complexity of cardiac rhythms during head-up tilt test by entropy of patterns

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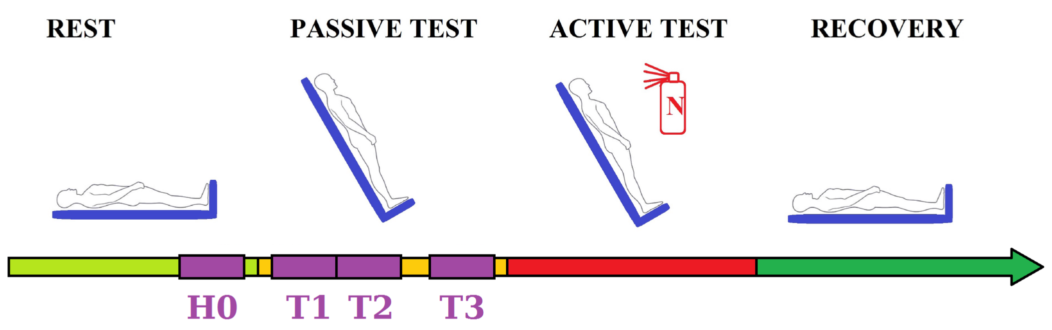
Head-up tilt test:

The head-up tilt (HUT) test is a valuable tool for provoking of dynamical changes in the cardiovascular system. In this context, time intervals between subsequent heart contractions (RR-intervals) and systolic blood pressure (SBP) were recorded during the HUT test. Then the four 300-point signals were extracted from each recording: window H0 corresponds to supine position before the tilt, windows T1 and T2 refer to early response to the tilt, and window T3 represents so called late response to the tilt.



Study group:

Study group

CG	VVS
28 healthy volunteers without fainting in history	59 patients with syncope in history
the HUT test: negative	the HUT test: positive

Permutation patterns:

Generation of permutation patterns:

1. $x^i = (x_i, x_{i+1}, \ldots, x_{i+L-1})$ – i-th segment of signal
2. In case of $L = 3$, we considered six permutation patterns:
   - $x_i \le x_{i+1} \le x_{i+2} \rightarrow$ [123]
   - $x_i \le x_{i+2} < x_{i+3} \rightarrow$ [132]
   - $x_{i+1} < x_i \le x_{i+2} \rightarrow$ [213]
   - $x_{i+1} \le x_{i+2} < x_i \rightarrow$ [231]
   - $x_{i+2} < x_i \le x_{i+1} \rightarrow$ [312]
   - $x_{i+2} < x_{i+1} < x_i \rightarrow$ [321]

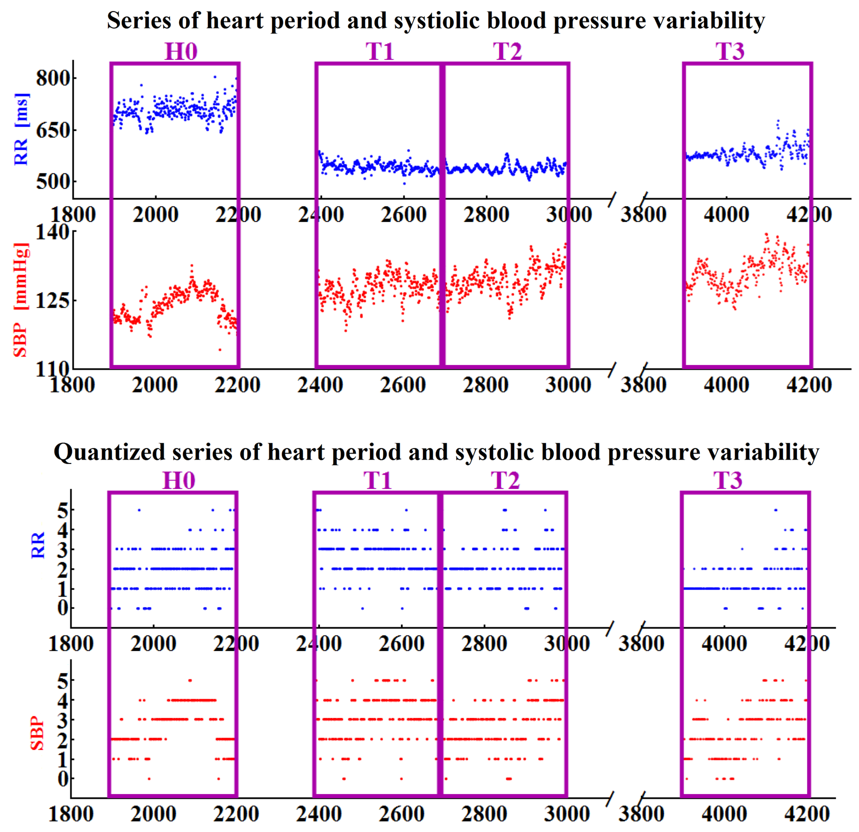
Examples:

1. $x^i = (808, 806, 816)$
   $806 < 808 < 816$
   $\Updownarrow \quad \rightarrow$ [213]
   $x_{i+1} < x_i \le x_{i+2}$
2. $x^i = (806, 816, 816)$
   $806 < 816 \le 816$
   $\Updownarrow \quad \rightarrow$ [123]
   $x_i \le x_{i+1} \le x_{i+2}$

Deterministic patterns:

Generation of deterministic patterns:

1. Quantization of time series into 6-value series



2. Classifying patterns into 4 groups:
   - 0V - constant pattern,
   - 1V - patterns contain a plateau and a ramp,
   - 2LV - patterns with two like variations,
   - 2UV - patterns with two unlike variations.

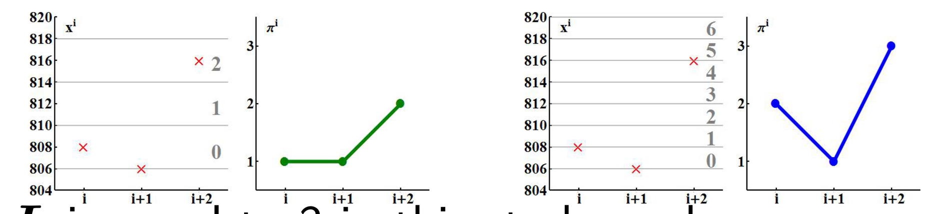
Ordinal patterns:

Generation of ordinal patterns:

1. Δ – segment resolution
2. $x^i = (x_i, x_{i+1}, \ldots, x_{i+L-1})$ – i-th segment of signal
3. $\phi^i = (\phi_i, \phi_{i+1}, \ldots, \phi_{i+L-1})$ – binned signal, where $\phi_{i+j} = \lfloor \frac{x_{i+j} - min(x^i)}{\Delta} \rfloor$ for $j = 0, 1, \ldots, L-1$
4. $\pi^i = (\pi_i, \pi_{i+1}, \ldots, \pi_{i+L-1})$ – ordinal pattern, which is constructed as follows: N different values of the ϕ^i are ranked and their ordinal values are assigned to π^i.

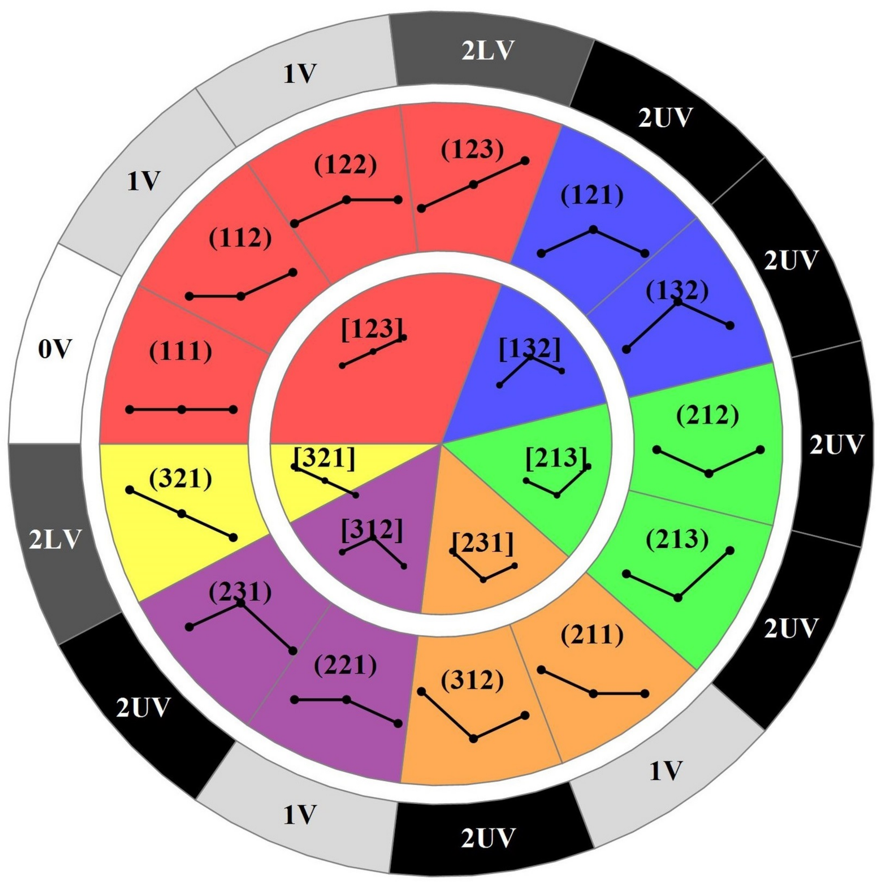
Example: $x^i = (808, 806, 816)$

$\Delta = 4$	$\Delta = 2$
$\phi^i = (0, 0, 2)$	$\phi^i = (1, 0, 5)$
$\pi^i = (1, 1, 2)$	$\pi^i = (2, 1, 3)$



L is equal to 3 in this study, and consequently we deal with 13 different ordinal patterns.

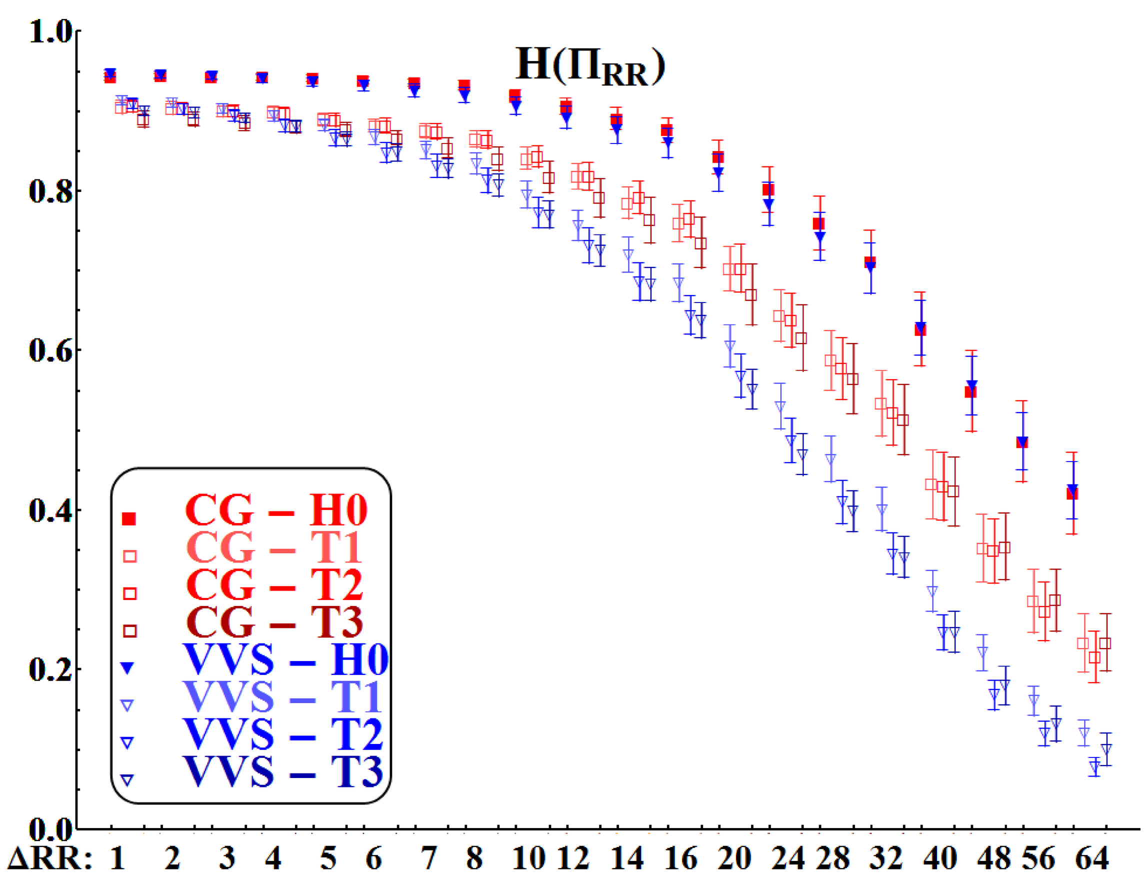
Relationships:

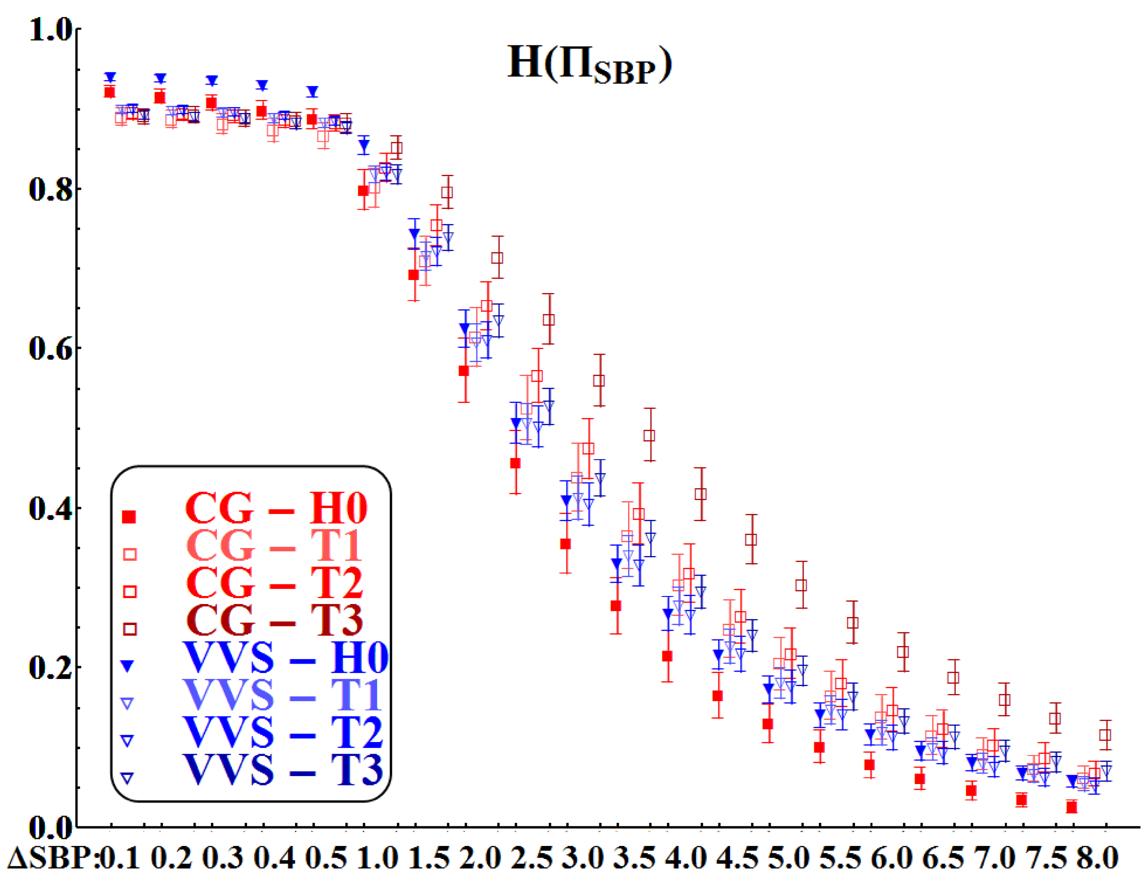


- permutation patterns - the center of the pie chart
- ordinal patterns - the middle ring of the pie char
- deterministic patterns - the external ring of the pie chart

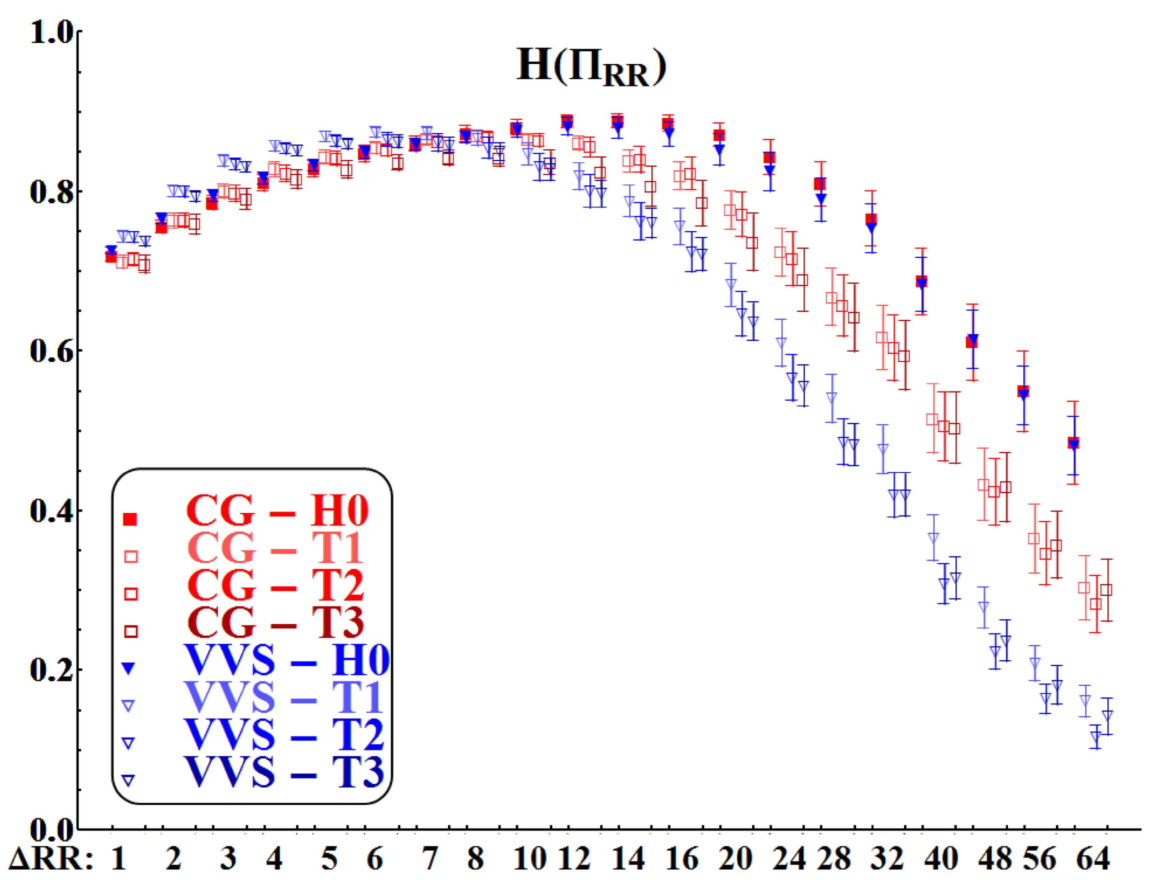
The Shannon entropy is calculated from distributions of these patterns found for RR-intervals ($H(\Pi_{RR})$) and the levels of SBP ($H(\Pi_{SBP})$).

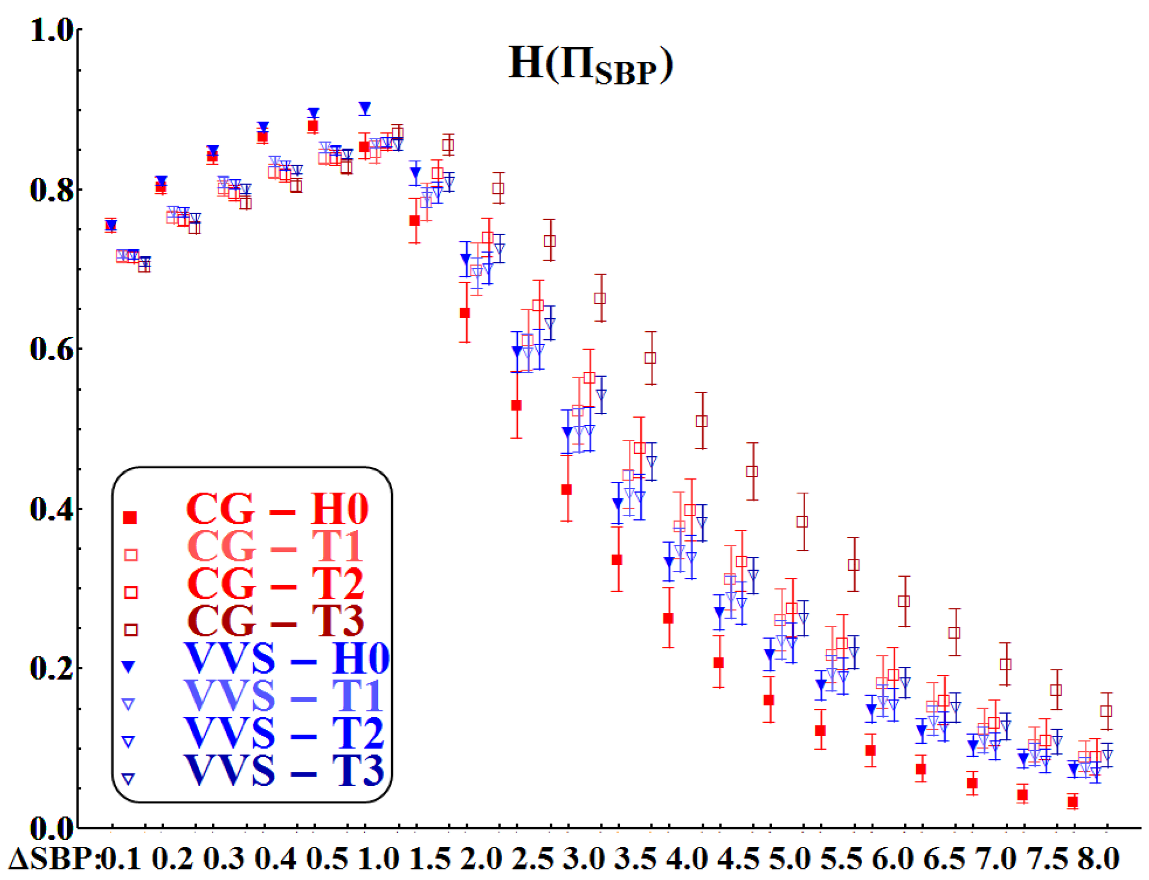
Shannon entropy of permutation patterns distribution:



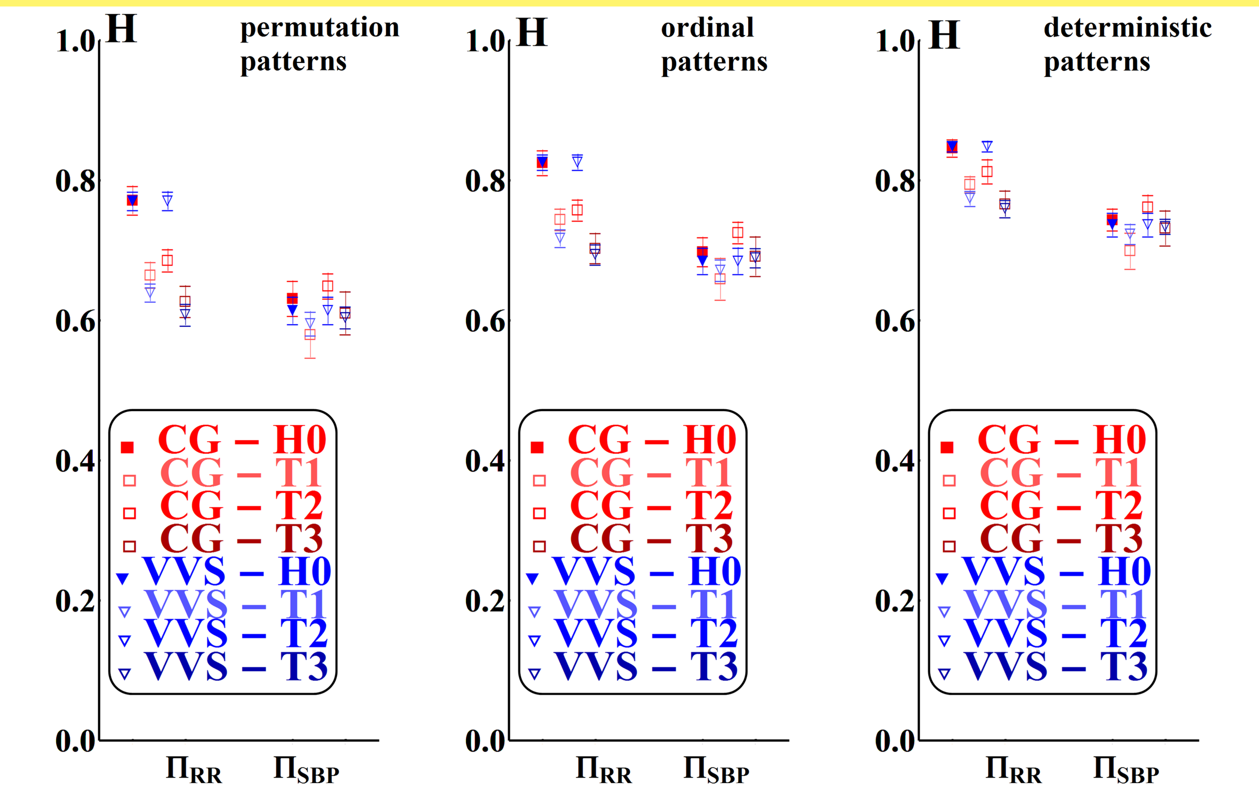


Shannon entropy of ordinal patterns distribution:





Shannon entropy of permutation, ordinal and deterministic patterns distribution:



Conclusion:

1. There is a statistical significant increase in the value of entropy of ordinal patterns when the resolution Δ_{RR} and Δ_{SBP} changes.
2. It corresponds to increasing occurrence of patterns with same values which are absent at the highest resolution.
3. At the maximum, the entropy for different groups of signals do not differ from each other.
4. In time windows T1, T2, and T3, the signal complexity of the healthy people is always higher than vasovagal patients, independently of the signal resolution for entropy of ordinal patterns and permutation patterns.
5. In case of the entropy calculated from signals represented by 6 symbols, the ordinal pattern approach provides a lower value of entropy than the permutation one.
6. The deterministic patterns give the lowest value of entropy.
7. However, the relations between entropy of deterministic patterns of different groups are the same as among entropy found for ordinal patterns.

References:

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