



# Beyond HRV. Extending the range of autonomic measures associated with heart rate variability – the effects of transcutaneous electroacupuncture (TEAS)

© David Mayor,<sup>a,1</sup> Deepak Panday,<sup>a</sup> Tony Steffert<sup>b</sup> and Hari Kala Kandel<sup>c</sup>.

a. University of Hertfordshire; b. MindSpire (CTO) & The Open University; c. Hertfordshire International College



## Background

Heart rate variability (HRV) is useful in acupuncture research as a measure of autonomic response. However, although it accurately reflects parasympathetic activity, there is less agreement on whether and how HRV can assess sympathetic activity. This study explores some potential autonomic measures beyond HRV that may do so, and investigates the effects of different frequencies and amplitudes of transcutaneous electroacupuncture (TEAS) on these measures.

## Objectives

- (1) To develop two open-access MATLAB graphical user interface (GUI) packages to facilitate accurate extraction of autonomic measures and their interrelationships from amplitudes and time intervals in up to four channels of simultaneously recorded ECG and other time series data.
- (2) To explore how such measures correlate with established HRV indices.
- (3) To assess to what extent these measures reflect the effects of differences in the frequency and/or amplitude of applied TEAS, age, gender and the passage of time.
- (4) To revisit the results of our previous research using these new data, incorporating corrections to data previously used.

## Methods

Data (around 2000 5-minute recordings,  $N = 66$ ) were gathered in a single-blind, semi-randomised cross-over study, as reported at the 2019 ARRC Symposium.

Our first GUI was created in MATLAB using standard methods, tested and revised until considered suited to extracting measures from raw ECG, BVP (blood volume pulse) and respiration data in a semi-automated manner. CEPS, our second GUI, is described elsewhere (<https://doi.org/10.3390/e23030321>).

More than 70 HRV, nonlinearity (HRNL) and other measures were explored on the basis of a literature review and allocated iteratively to PNS-like, SNS-like and two other groupings using correlations (Spearman's  $\rho$ ), and then a more formal factor analysis. 75 complexity and entropy measures from CEPS were also investigated.

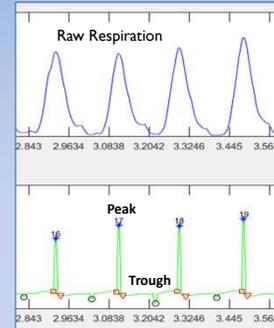
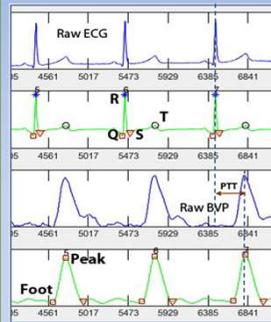
Further information available at [http://electroacupuncture.qeeg.co.uk/PNS\\_SNS](http://electroacupuncture.qeeg.co.uk/PNS_SNS), also accessible through the QR code at the head of this poster.

## Physiological signals used

(ECG, BVP and Respiration)

Signals were processed to obtain amplitude and interval data:

- R amplitude (Rsa)
- T amplitude (Ta)
- RR interval (RRi)
- QT interval (QTi)
- Pulse transit time (PTT)
- BVP amplitude (PWA)
- BVP Systolic interval (Si)
- Resp amplitude (PT/TP ratio) etc.



## MAIN RESULTS

**Groupings (2020).** The following allocations of 'new' (non-HRV) measures were consistent both pre- and post-TEAS:

PNS-like	SNS-like	Ambivalent
<ul style="list-style-type: none"> <li>Finger temperature variability (coefficient of variation, CV)*</li> <li>Outbreath-to-inbreath interval (O/I) ratio</li> </ul>	<ul style="list-style-type: none"> <li>T-wave amplitude CV</li> <li>Finger temperature (TEMP)</li> <li>Cardiac coherence ratio</li> <li>Outbreath CV*</li> <li>O/I ratio CV*</li> <li>Respiratory amplitude CV</li> </ul>	<ul style="list-style-type: none"> <li>R-wave amplitude CV</li> <li>Pulse transit time (PTT) CV</li> </ul>

Most of these measures increased or decreased consistently, regardless of stimulation frequency. As for conventional HRV, effect sizes (Cohen's  $d$ ) for pre-post differences were **at best small**, 0.2-0.4 (\*).

**Groupings using CEPS (2021).** On the basis of strong correlations at baseline ( $\rho > 0.8$ ), Tone-Entropy (T-E) 'Entropy' and extended Poincaré Plot measures SD1 and SD2 could be considered PNS-like, Slope entropy and T-E 'Tone' SNS-like. These allocations remain to be confirmed. For T-E, pre-post effect sizes could be **large** ( $>0.8$ ), or **even 'huge'** ( $>1.0$ ).

Greatest numbers of large/huge effect sizes were found in the QT<sub>i</sub> and systolic interval (Si) data for differences between high and low amplitude stimulation (43.1% and 31.1% of CEPS measures tested), and for age (younger/older) in the PTT data (39.3%) and pulse wave amplitude data (33.0%). Gender showed greatest effect on CEPS measures in the PWA data (but only for 9.3%). Using conventional RR<sub>i</sub> HRV measures for the same comparisons, far fewer large effect sizes were found ( $< 9.0\%$  of measures tested in each case).

**Take-home message.** Future research into the autonomic effects of acupuncture could explore using nonlinear measures of complexity and entropy, applying them not only to the usual ECG RR or BVP peak-to-peak interval data, but also to interval and amplitude data such as QT<sub>i</sub>, Si, Rsa and PWA.

## Some other results

- Frequency.** The main linear non-HRV measures showing significant differences for stimulation frequency post-stimulation were T-wave amplitude, PTT CV, BVP CV and TEMP. (Frequency-dependent changes in the nonlinear CEPS measures were not fully investigated.)
- Change over time.** Those linear measures showing significant ratios of increases to decreases ( $>1$ ) from baseline included BVP, PTT and PTT CV, with significant decreases (ratios  $< 1$ ) for T-wave and S-to-T amplitudes.
- Amplitude.** QT, RT and ST intervals decreased more with high than low amplitude stimulation at 10 pulses per second (pps). Differences in QT<sub>i</sub>-derived CEPS measures were marked.
- TEMP increased more with high than low amplitude stimulation at 80 pps.
- Both PNS- and SNS-like measures decreased more often than increased with high amplitude stimulation, whereas with low amplitude stimulation similar numbers of PNS-like measures increased and decreased, but more SNS-like measures decreased than increased.
- Comparison with previous results.** Some of our prior results were confirmed in the present analysis, for instance that stimulation at 2.5 pps may result in greater fingertip blood flow than at 10 pps or 80 pps, and at 80 pps in longer pulse transit time (PTT) than at 2.5 pps or 10 pps.
- We again observed that stimulation at 10 pps may be experienced as less stressful than at 2.5 or 80 pps, for both linear and nonlinear non-HRV measures.
- Age and gender.** 82% of PNS-like measures were higher in younger than older individuals, and in women rather than men. 73% of SNS-like measures were higher in men than women, and 69% higher in older than younger participants.

## Limitations and future directions

When planning this study, we were not aware that HRV on its own cannot provide unequivocal insights into the workings of the SNS. To have included a known index of SNS activity in our study design could have provided a benchmark with which to assess the validity of our proposed 'SNS-like' measures, which require further validation.

David Mayor, acupuncture researcher  
<http://electroacupuncture.qeeg.co.uk/>  
davidmayor@welwynacupuncture.co.uk

Tony Steffert, neurofeedback specialist  
<http://qeeg.co.uk/>  
tony@qeeg.co.uk



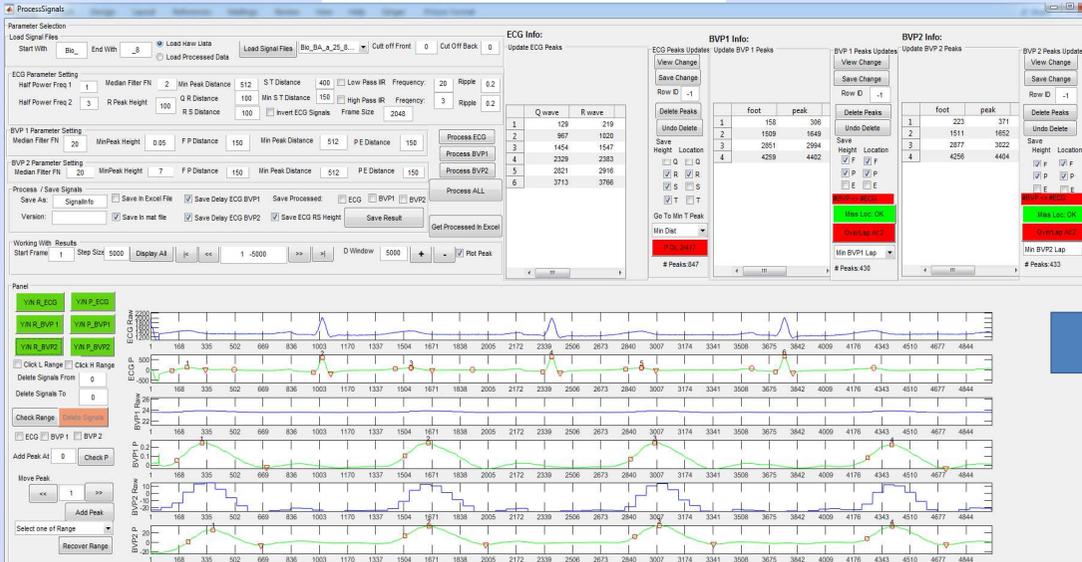
# Beyond HRV. Extending the range of autonomic measures associated with heart rate variability – the effects of transcutaneous electroacupuncture (TEAS)

© David Mayor,<sup>a,1</sup> Deepak Panday,<sup>a</sup> Tony Steffert<sup>b</sup> and Hari Kala Kandel<sup>c</sup>.

a. University of Hertfordshire; b. MindSpire (CTO) & The Open University; c. Hertfordshire International College

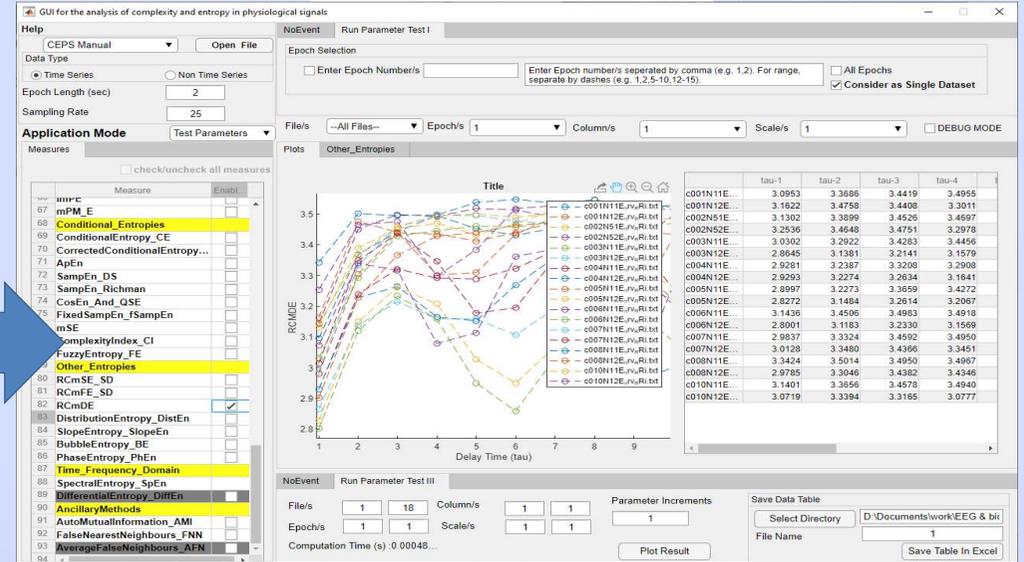


## ProcessSignals



*ProcessSignals* GUI designed to detect ECG, BVP and Respiration peaks. Software still in development, but available with poster submitted for a cancelled 2020 conference at: <https://bitbucket.org/mLearning/signalprocessing>.

## CEPS



*CEPS* GUI for the analysis of complexity and entropy in physiological signals. Software, together with manual and other supporting literature, available at: [https://bitbucket.org/deepak\\_panday/pipeline/src/pipeline\\_V2/](https://bitbucket.org/deepak_panday/pipeline/src/pipeline_V2/).

URL for this presentation

[http://electroacupuncture.qeeg.co.uk/PNS\\_SNS](http://electroacupuncture.qeeg.co.uk/PNS_SNS)

**Electroacupuncture**  
investigating the effects of electroacupuncture on the eeg and heart rate variability  
David Mayor & Tony Steffert

---

Electroacupuncture



The Effects of Electroacupuncture (EA) and Transcutaneous Electrical Nerve Stimulation (TENS) on the EEG and Heart Rate Variability

This study, by David Mayor and Tony Steffert, was first proposed in 2001, and has been in progress since Summer 2011. Here you can find some formal and informal reports, updates and background information (in date order).

Further information available at [http://electroacupuncture.qeeg.co.uk/PNS\\_SNS](http://electroacupuncture.qeeg.co.uk/PNS_SNS), also accessible through the QR code at the head of this poster.

David Mayor, acupuncture researcher  
<http://electroacupuncture.qeeg.co.uk/>  
davidmayor@welwynacupuncture.co.uk

Tony Steffert, neurofeedback specialist  
<http://qeeg.co.uk/>  
tony@qeeg.co.uk



# Beyond HRV. Extending the range of autonomic measures associated with heart rate variability – the effects of transcutaneous electroacupuncture (TEAS)

© David Mayor,<sup>a,1</sup> Deepak Panday,<sup>a</sup> Tony Steffert<sup>b</sup> and Hari Kala Kandel<sup>c</sup>.

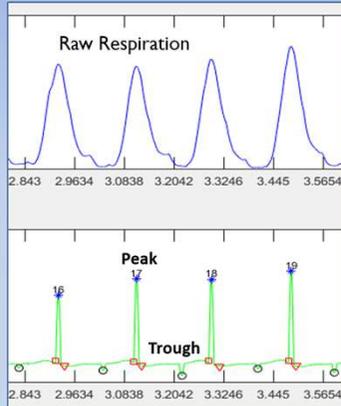
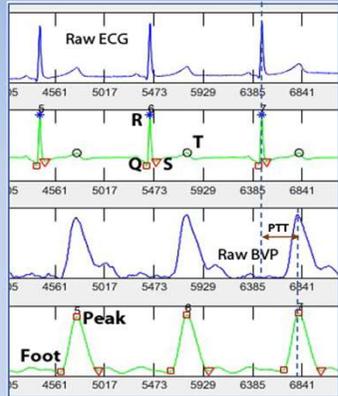
a. University of Hertfordshire; b. MindSpire (CTO) & The Open University; c. Hertfordshire International College



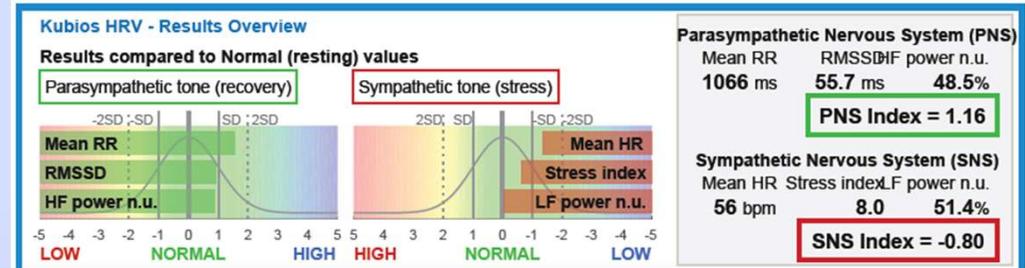
## Physiological signals used

(ECG, BVP and Respiration)  
Signals were processed to obtain amplitude and interval data:

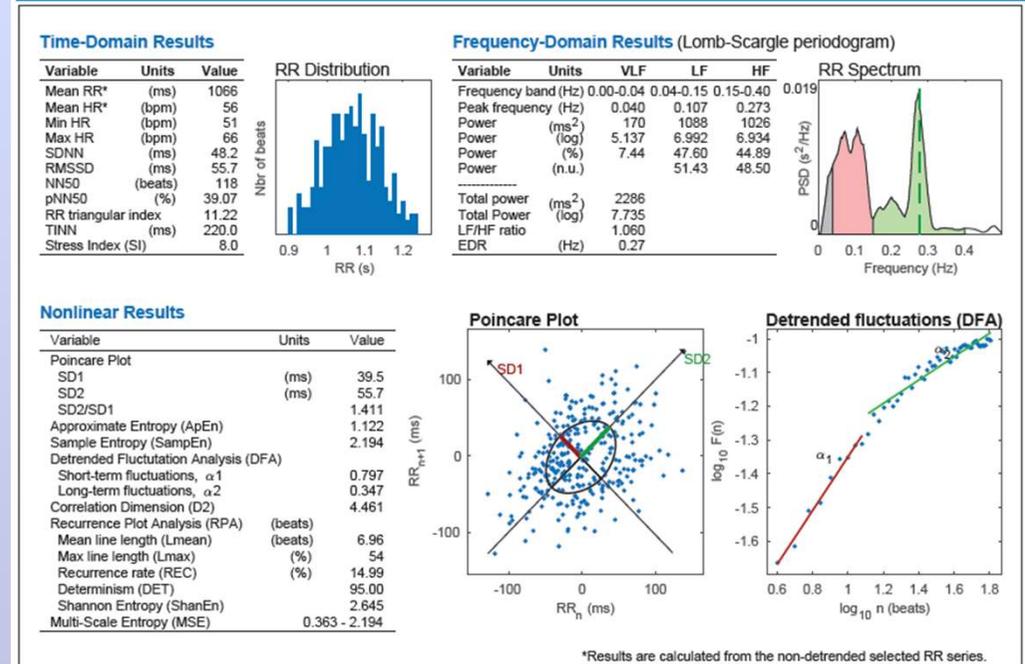
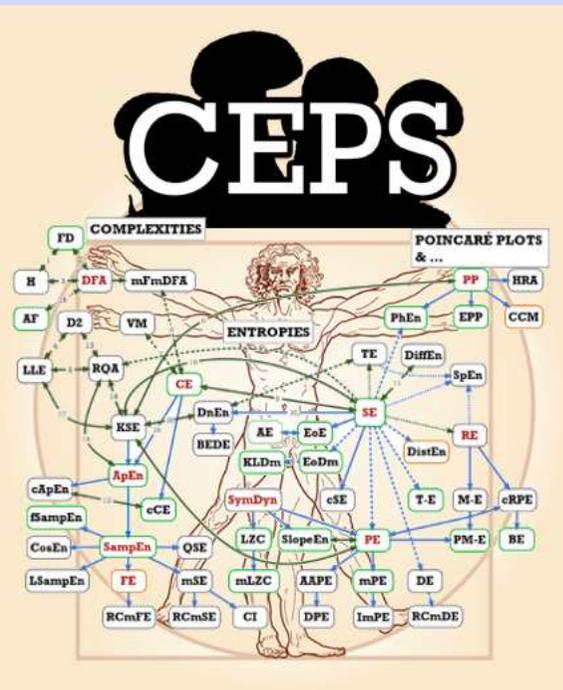
- R amplitude (Rsa)
- T amplitude (Ta)
- RR interval (RRi)
- QT interval (QTi)
- Pulse transit time (PTT)
- BVP amplitude (PWA)
- BVP Systolic interval (Si)
- Resp amplitude (PT/TP ratio)
- etc.



*Output from Kubios HRV software*  
Showing time- and frequency-domain measures, nonlinear measures and a Poincaré plot.



*Some complexity and entropy measures available in CEPS*  
<https://doi.org/10.3390/e23030321>





# Beyond HRV. Extending the range of autonomic measures associated with heart rate variability – the effects of transcutaneous electroacupuncture (TEAS)

© David Mayor,<sup>a,1</sup> Deepak Panday,<sup>a</sup> Tony Steffert<sup>b</sup> and Hari Kala Kandel<sup>c</sup>.

a. University of Hertfordshire; b. MindSpire (CTO) & The Open University; c. Hertfordshire International College



## MAIN RESULTS

**Groupings (2020).** The following allocations of ‘new’ (non-HRV) measures were consistent both pre- and post-TEAS:

PNS-like	SNS-like	Ambivalent
<ul style="list-style-type: none"> <li>•Finger temperature variability (coefficient of variation, CV)*</li> <li>• Outbreath-to-inbreath interval (O/I) ratio</li> </ul>	<ul style="list-style-type: none"> <li>•T-wave amplitude CV</li> <li>•Finger temperature (TEMP)</li> <li>•Cardiac coherence ratio</li> <li>•Outbreath CV*</li> <li>•O/I ratio CV*</li> <li>•Respiratory amplitude CV</li> </ul>	<ul style="list-style-type: none"> <li>•R-wave amplitude CV</li> <li>•Pulse transit time (PTT) CV</li> </ul>

Most of these measures increased or decreased consistently, regardless of stimulation frequency. As for conventional HRV, effect sizes (Cohen’s *d*) for pre-post differences were **at best small**, 0.2-0.4 (\*).

**Groupings using CEPS (2021).** On the basis of strong correlations at baseline ( $\rho > 0.8$ ), Tone-Entropy (T-E) ‘Entropy’ and extended Poincaré Plot measures SD1 and SD2 could be considered PNS-like, Slope entropy and T-E ‘Tone’ SNS-like. These allocations remain to be confirmed. For T-E, pre-post effect sizes could be **large** (>0.8), or even ‘**huge**’ (>1.0).

Greatest numbers of large/huge effect sizes were found in the QT<sub>i</sub> and systolic interval (Si) data for differences between high and low amplitude stimulation (43.1% and 31.1% of CEPS measures tested), and for age (younger/older) in the PTT data (39.3%) and pulse wave amplitude data (33.0%). Gender showed greatest effect on CEPS measures in the PWA data (but only for 9.3%).

Using conventional RR<sub>i</sub> HRV measures for the same comparisons, far fewer large effect sizes were found (< 9.0% of measures tested).

**Take-home message.** Future research into the autonomic effects of acupuncture could explore using nonlinear measures of complexity and entropy, applying them not only to the usual ECG RR or BVP peak-to-peak interval data, but also to interval and amplitude data such as QT<sub>i</sub>, Si, RSa and PWA.



# Beyond HRV. Extending the range of autonomic measures associated with heart rate variability – the effects of transcutaneous electroacupuncture (TEAS)

© David Mayor,<sup>a,1</sup> Deepak Panday,<sup>a</sup> Tony Steffert<sup>b</sup> and Hari Kala Kandel<sup>c</sup>.

a. University of Hertfordshire; b. MindSpire (CTO) & The Open University; c. Hertfordshire International College



## Some other results

- **Amplitude.** QT, RT and ST intervals decreased more with high than low amplitude stimulation at 10 pulses per second (pps). Differences in QT<sub>i</sub>-derived CEPS measures were marked.
- TEMP increased more with high than low amplitude stimulation at 80 pps.
- Both PNS- and SNS-like measures decreased more often than increased with high amplitude stimulation, whereas with low amplitude stimulation similar numbers of PNS-like measures increased and decreased, but more SNS-like measures decreased than increased.
- **Comparison with previous results.** Some of our prior results were confirmed in the present analysis:
  - Stimulation at 2.5 pps may result in greater fingertip blood flow than at 10 pps or 80 pps, and at 80 pps in longer pulse transit time (PTT) than at 2.5 pps or 10 pps.
  - We again observed that stimulation at 10 pps may be experienced as less stressful (i.e. with lower SNS-like indices) than at 2.5 or 80 pps, for both linear and nonlinear non-HRV measures.
- **Age and gender.** 82% of PNS-like measures were higher in younger than older individuals, and in women rather than men. 73% of SNS-like measures were higher in men than women, and 69% higher in older than younger participants.

## Limitations and future directions

When planning this study ten years ago, we were not aware that HRV on its own cannot provide unequivocal insights into the workings of the SNS. To have included a known index of SNS activity in our study design could have provided a benchmark with which to assess the validity of our proposed ‘SNS-like’ measures, which require further validation. There is always more to do.