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Quantifying Cooperation in Choir Singing: Respiratory and Cardiac Synchronisation

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Introduction – Choir singing

http://www.musicprods.co.uk/wp-content/uploads/2014/09/Eric-Whitacre-31479-900x471_EricWhitacre-DN-6786-Soc_197938.jpg

‘Human instruments’: soprano, alto, tenor, bass

Breathing in unison is required, dictated by the tempo of a musical score

=> synchrony in respiratory and cardiac activity

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Introduction – Terminologies

Breathing rhythms of singers

voluntarily controlled to perform long/short inhalation/exhalation

involuntarily controlled by the **autonomic nervous system (ANS)**

Sympathetic nervous system (SNS) ***accelerates*** physiological responses, namely blood pressure and ***heart rate***, in ***stressful*** conditions

Parasympathetic nervous system (PNS) ***decelerates*** physiological responses in ***resting*** conditions

The interplay between SNS and PNS manifests in variations of the timing of the cardiac cycle – **heart rate variability (HRV)**

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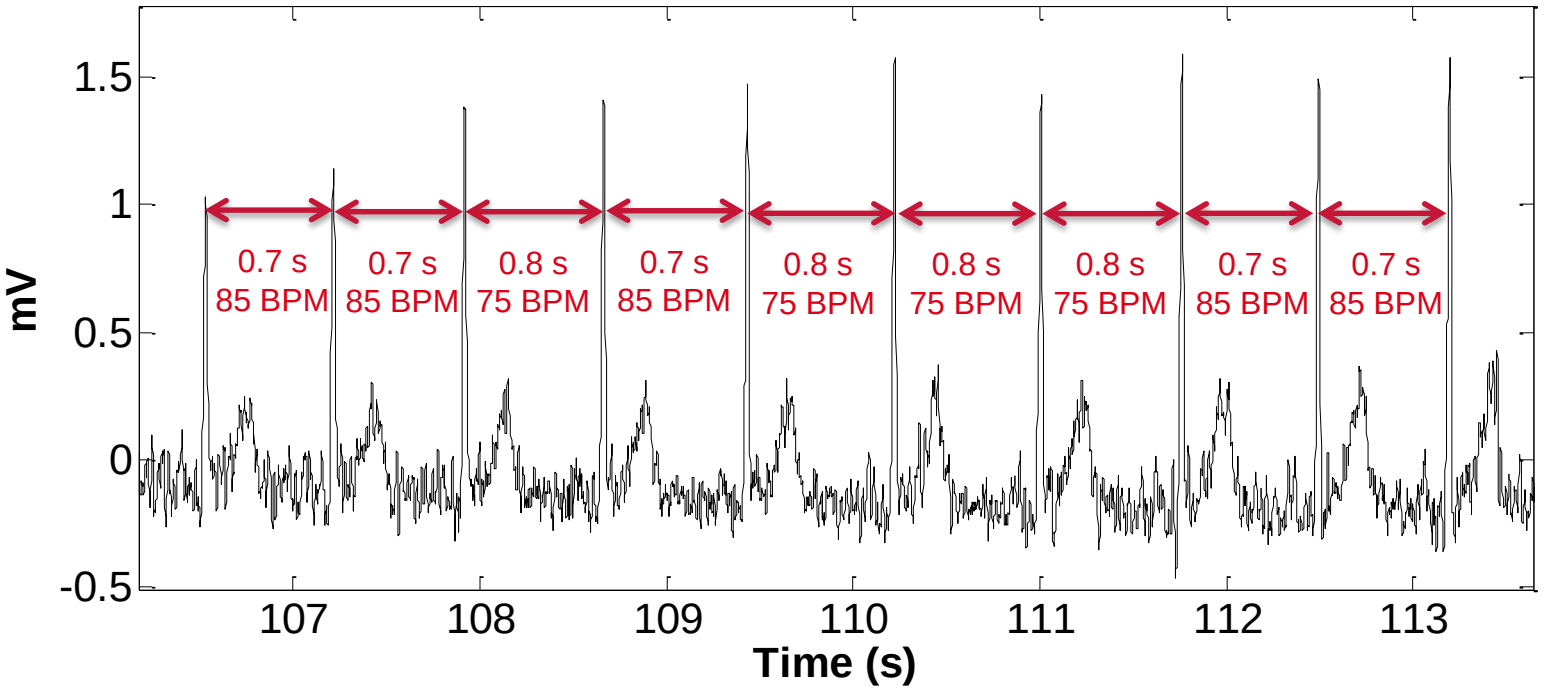
Introduction – Electrocardiogram (ECG) & Heart rate variability (HRV)



HRV is also modulated by breathing – respiratory sinus arrhythmis (RSA), heart rate accelerates during inspiration and decelerates during expiration. RSA is usually attributed to the activity of PNS.

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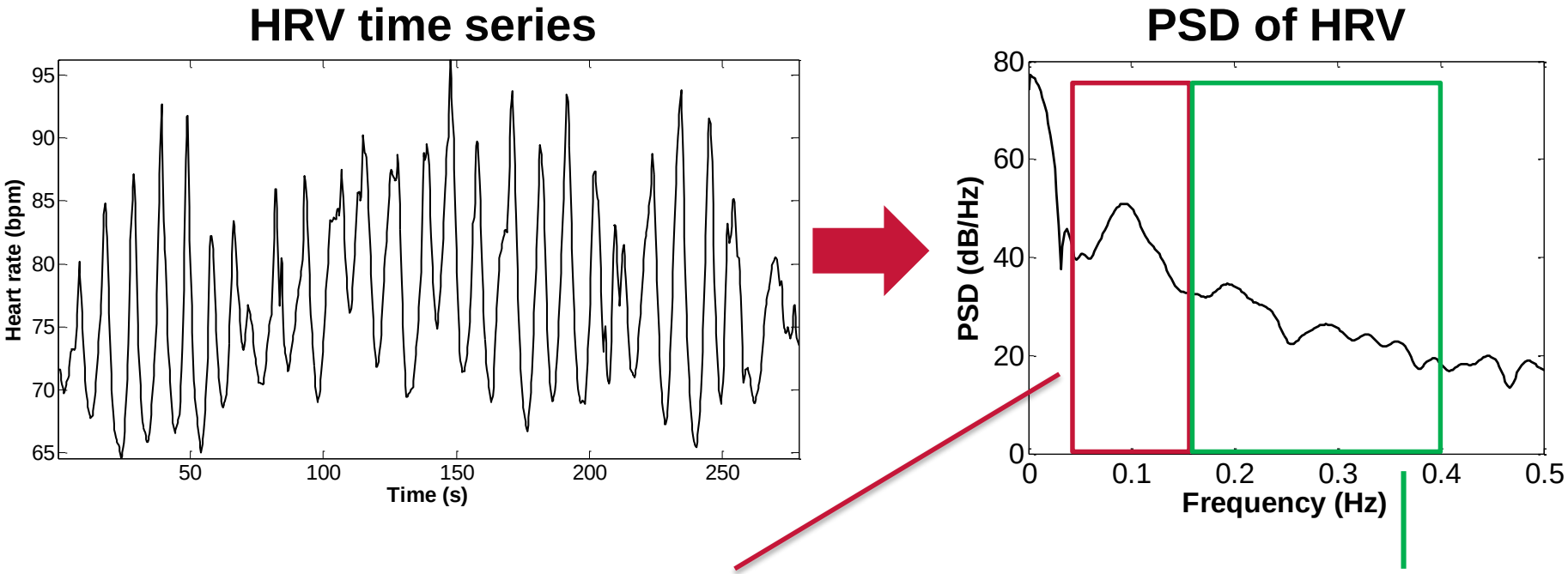
Introduction – Heart rate variability (HRV)



Low frequency (LF) component (0.04-0.15 Hz) – interaction of SNS & PNS

High frequency (HF) component (0.15-0.4 Hz) reflects the activity of PNS, dominated by changes in heart rate induced by breathing

Introduction – Signal decomposition

Noise-assisted multivariate empirical mode decomposition (NA-MEMD)

• Adaptive, data-driven method for the analysis of nonlinear and nonstationary time series

• Adaptively decomposes a given multivariate signal via the sifting process into multiple narrow-band AM/FM components, referred to as intrinsic mode functions (IMFs) and used as bases

• White Gaussian noise (WGN) helps reduce mode-mixing, the phenomenon where different oscillatory components appear in a single IMF.

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Introduction – Data-association measures

Intrinsic coherence (ICoh) - quantifies phase and amplitude relationships between 2 IMFs as a function of frequency,

$$COH_{ij}(f) = \left| \frac{S_{ij}(f)}{\sqrt{S_{ii}(f)S_{jj}(f)}} \right|^2$$

0: non-coherent relationship
1: perfect coherence

$S_{ij}(f)$: cross-spectral power density of $x_i(t)$ & $x_j(t)$, $S_{ii}(f)$ & $S_{jj}(f)$: power spectral densities of $x_i(t)$ & $x_j(t)$

Intrinsic phase synchrony - quantifies phase relationship between 2 IMFs using the phase synchronisation index (PSI),

$$\rho(t) = \frac{S_{max} - S}{S_{max}}$$

0: non-phase-synchronous relationship
1: perfect phase locking

S: Shannon entropy of the distribution of phase differences, S_{max}: maximum entropy

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Introduction - Objective

To characterise dependencies in the ***respiratory*** and ***HRV*** signals of:

- Choir during a rehearsal and a real performance
- The conductor in both of these situations
- A subset of audience during the performance

The investigation promises new, objective measures of the degree of human cooperation.

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Data acquisition

Respiratory and ***ECG*** signals were recorded during a 5-minute music piece during rehearsal and performance:

- Conductor
- 5 choir members
- 5 audience members

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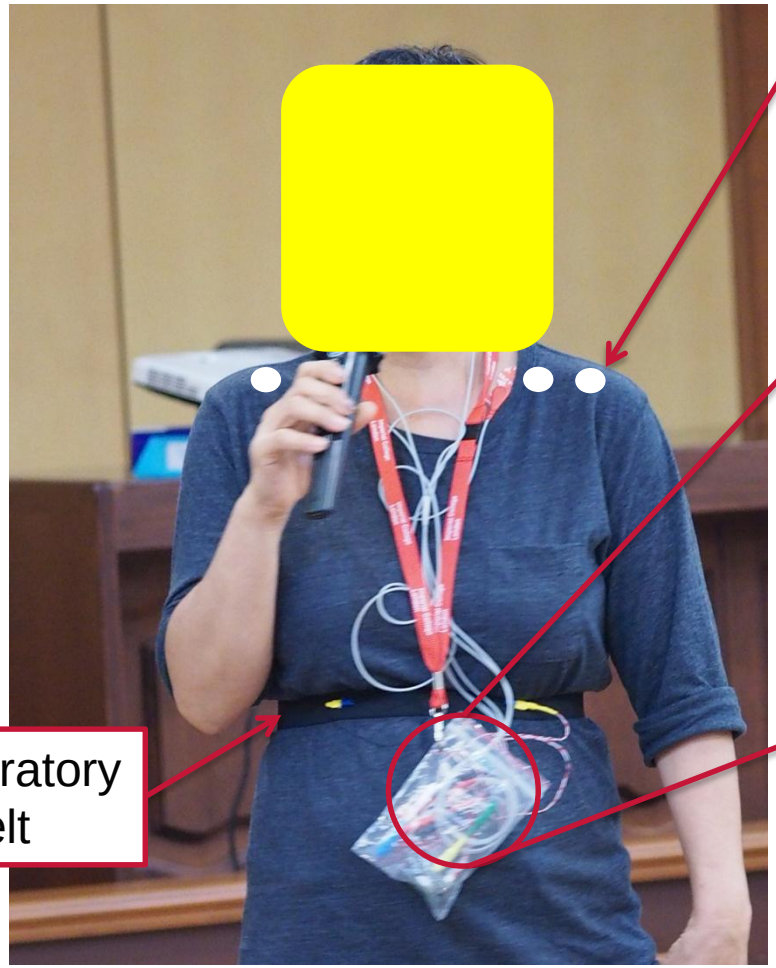
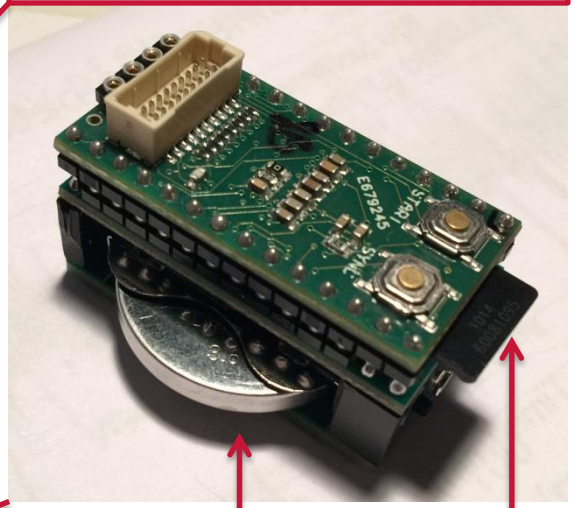
Data acquisition – iAmp (physiological data logger)



3 electrodes

8-channel data logger



Micro-SD card

Rechargeable coin cell battery

Respiratory belt

Synchrony analysis – Data formation & decomposition

•The respiratory or HRV signals of the conductor and the 5 members of the choir/audience during both the rehearsal and/or the performance were separately used to form 6-channel data which was decomposed using NA-MEMD with 10 adjacent WGN channels.

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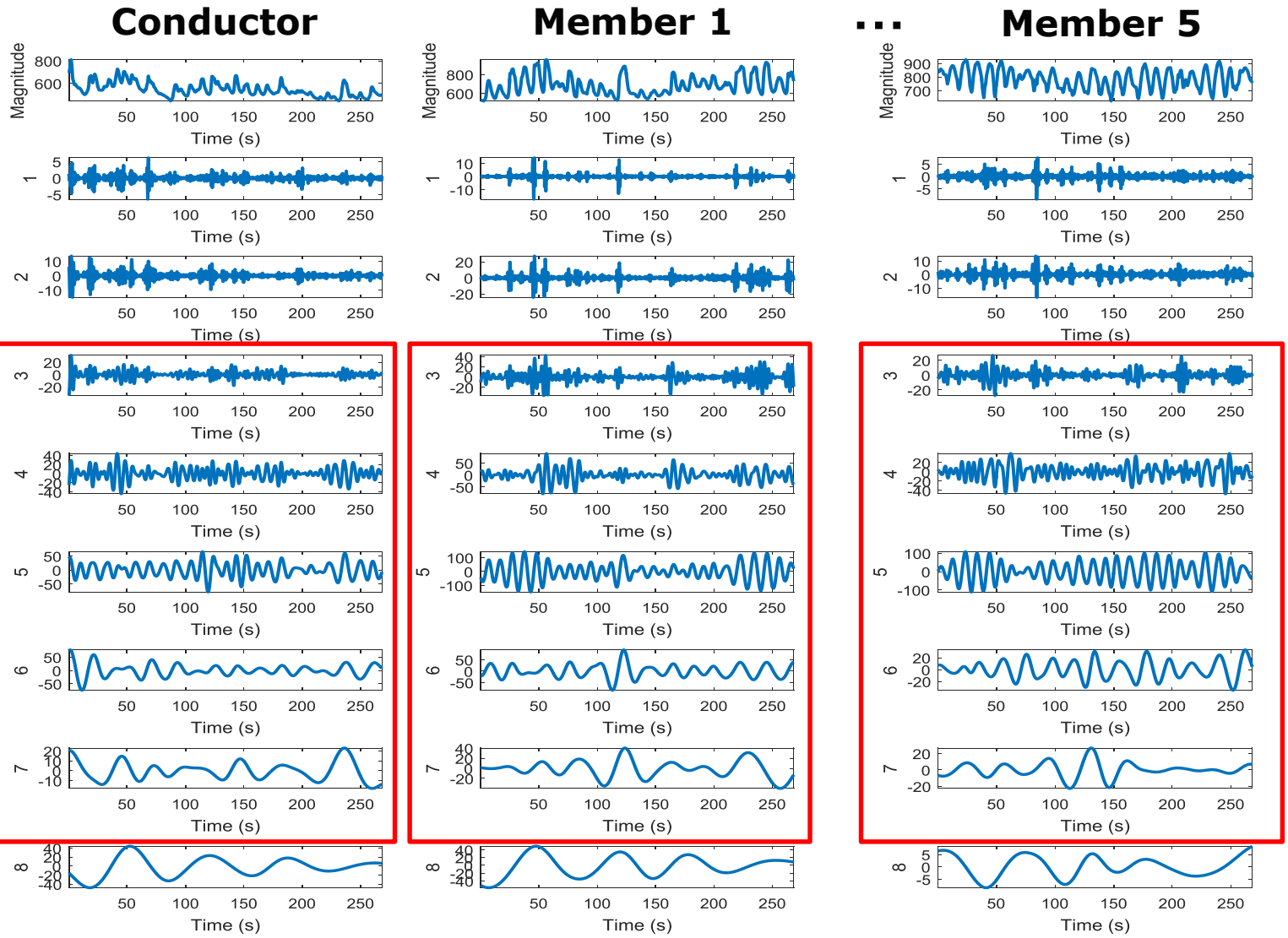
Synchrony analysis – HRV signals & IMFs



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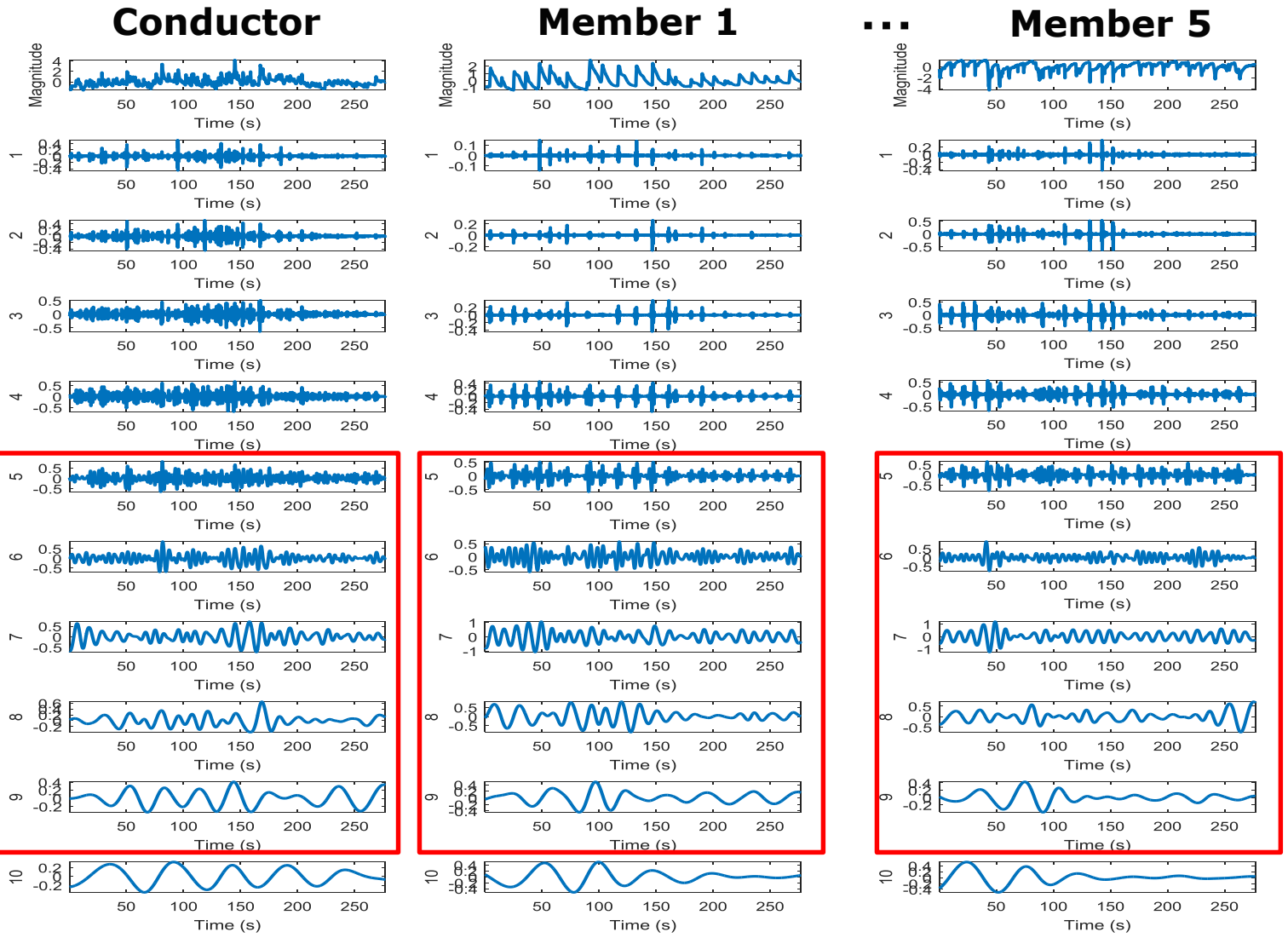
Synchrony analysis – Respiratory signals & IMFs

Original signal

Full band of interest, 0.04-0.4 Hz, summed IMFs 5-9



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Synchrony analysis – PSI & COH estimation

The PSI and COH indices of the respiratory and HRV IMFs were estimated in 6 categories:

1. Among the 5 members of the choir during the rehearsal.
2. Among the 5 members of the choir during the performance.
3. Among the 5 members of the audience during the performance.

•**(Within-group estimation)**

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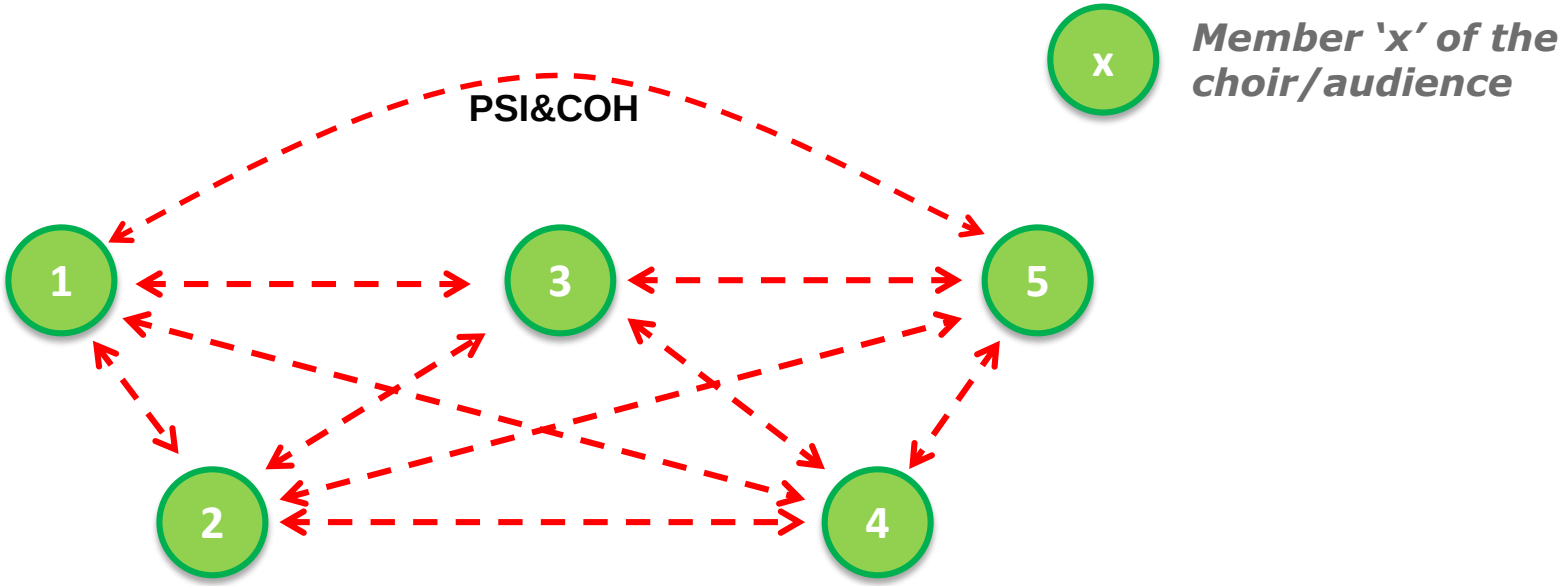
Synchrony analysis – Within-group estimation of PSI&COH



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Synchrony analysis – PSI & COH estimation

4. Between the conductor and the 5 members of the choir during the rehearsal.

5. Between the conductor and the 5 members of the choir during the performance.

6. Between the conductor and the 5 members of the audience during the performance.

- **(Between-group estimation)**

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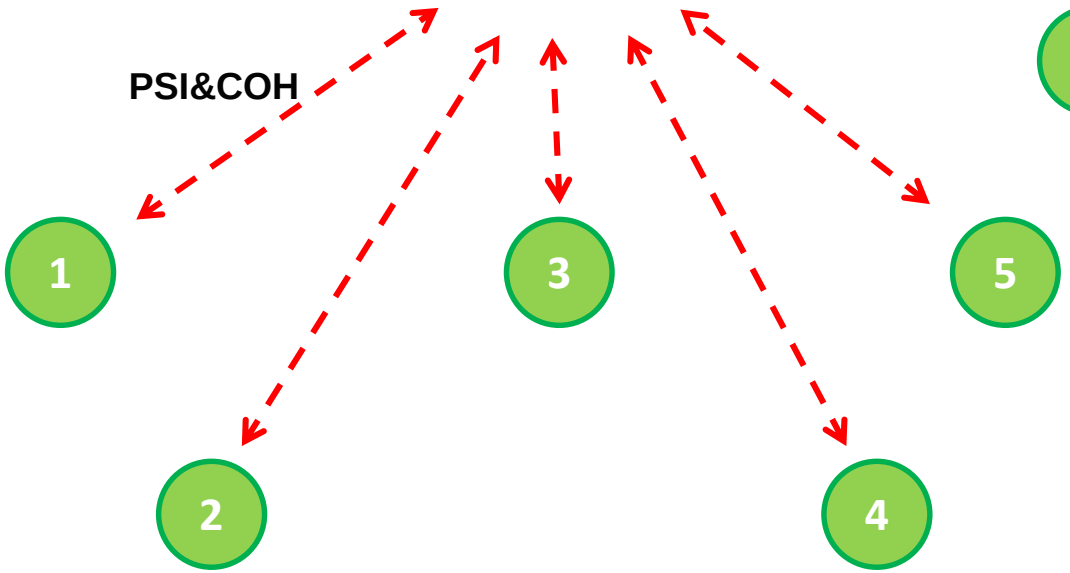
Synchrony analysis – Between-group estimation of PSI&COH



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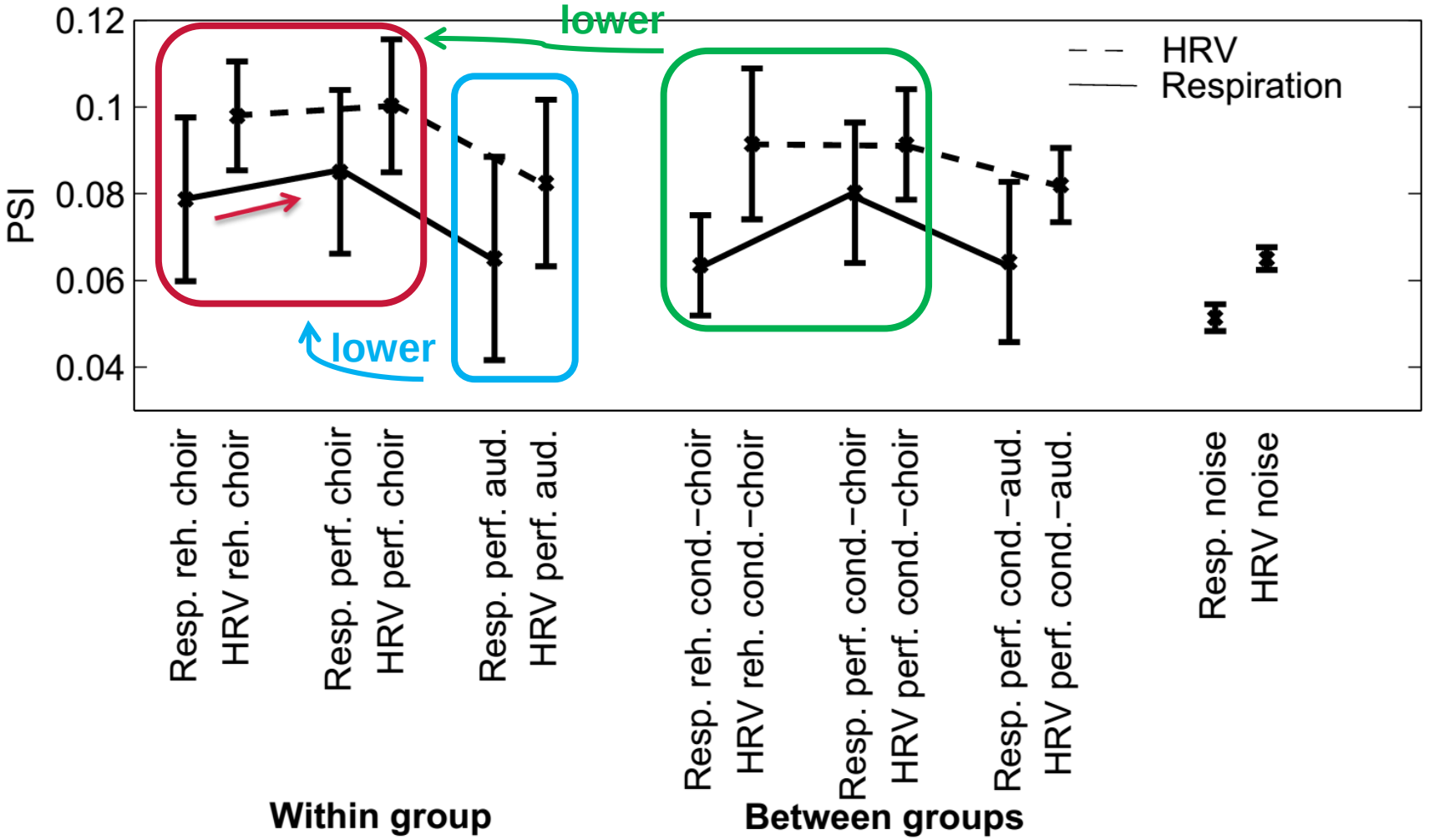
Results – PSI values



PSI values were obtained from 50 realisations of NA-MEMD, and the Z-test at a significance level of 0.05 was performed.

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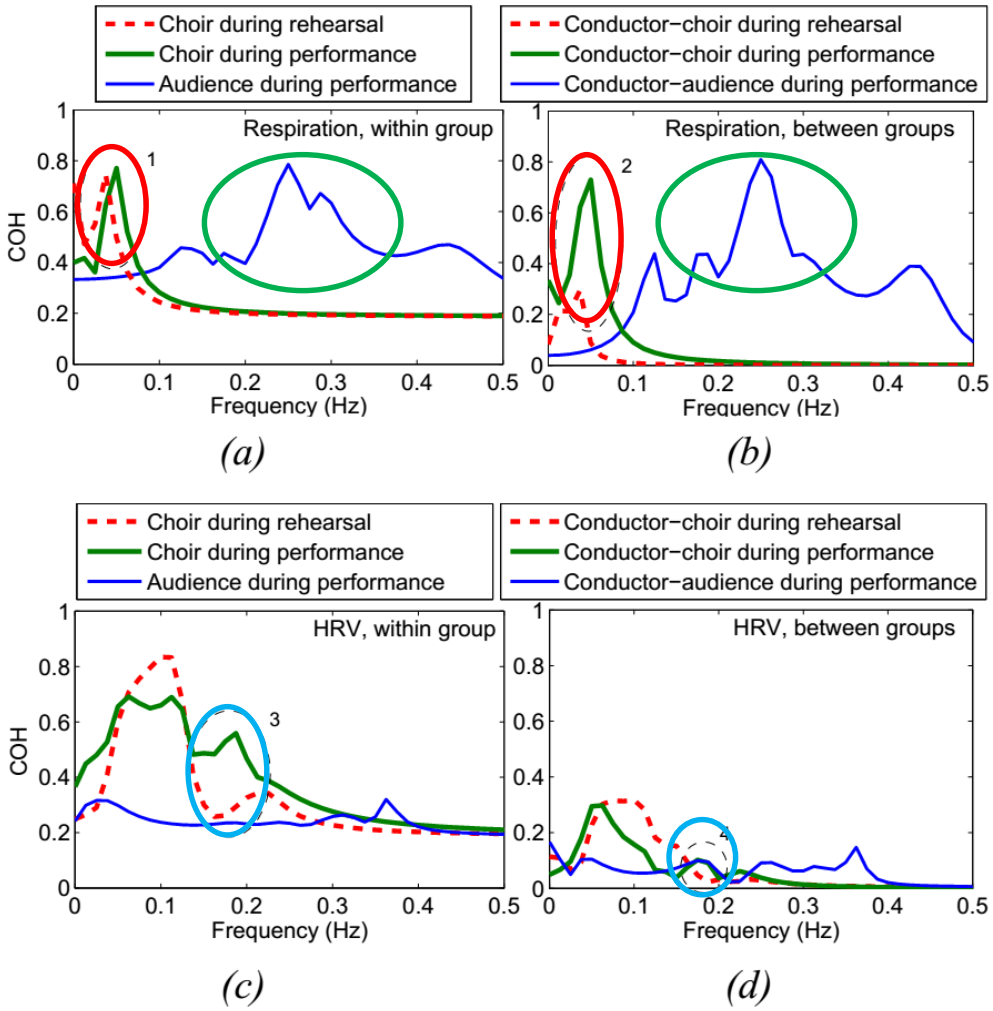
Results – COH values



- High coherence in long exhalation between the members of the choir due to controlled breathing while singing
- High conductor-choir coherence in long exhalation during performance
- High coherence in normal breathing within the audience and between the conductor and the audience
- Higher coherence in HF band of HRV within the choir mediated by respiration via RSA
- No coherence in HRV between the members of the audience

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Conclusions

• This study has employed intrinsic phase synchrony and intrinsic coherence to quantify phase and amplitude relationships in the respiratory and cardiac signals of the choir, the conductor and the audience, in order to investigate degrees of cooperation during a social task.

• Each group is represented by a distinctive degree of joint synchronisation of participants' physiological responses.

• Intrinsic phase synchrony has captured phase relationship of both physiological signals in all situations effectively, yielding a meaningful and straightforward to interpret data association metric.

• We have also illuminated the coherence effects between the sympathetic and parasympathetic nervous systems in the participants, primarily mediated by respiration; these could not be found using intrinsic phase synchrony, however, the coherence is less amenable to physical interpretation.

• Both the considered intrinsic measures have designated a quantitative approach to assessing joint endeavours, and have paved the way for mathematical characterisation of cooperative physiological systems across human activities.

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Acknowledgement

We wish to thank the Eric Whitacre Choir who participated in our study, during their concert at Union Chapel, London, UK in February 2015.

Thank you