Complexity as cardiorespiratory coupling measure in neonates with different gestational ages

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Objective

After the transition from fetal to neonatal life, the cardio-respiratory system needs to adapt to the extrauterine condition. Both the cardiac and respiratory systems display complex dynamics. This study aimed to investigate the relationship between cardiorespiratory coupling, heart rate variability (HRV), and respiration of neonatal with gestational age (GA).

Several complexity measures have been developed to quantify the complexity of physiological signals. In this study, we applied sample entropy (SampEn) and the bzip2 compressor to the time series. The mutual information (MI) and the normalized compression distance (NCD) were used to quantify the complexity of the cardiorespiratory coupling.

Methods

Entropy → Sample Entropy [1]

$X = \{x_i\}$ of N points

$$SampEn = -ln\frac{A}{B}$$

A – The number of vector pairs of length $m+1$ having $d[X_{m+1}(i), X_{m+1}(j)] \leq r$, with $i \neq j$

B – The total number of template matches of length m also with $i \neq j$

Mutual Information [2]

$$I(X,Y) = \sum_i \sum_j p_{X,Y}(i,j) log \frac{p_{X,Y}(i,j)}{p_X(i) p_Y(j)}$$

X and Y – Time series

$p_{X,Y}(i,j)$ – Joint probability density function of X and Y

$p_X(i)$ – Marginal probability mass functions of X

Compression [3] → bzip2

↑ Approximation

Kolmogorov Complexity (Not computable)

$$K_\Phi(x) = \begin{cases} min\{|p| : \Phi(p) = x\} & \text{if such } p \text{ exists} \\ \infty & \text{if } p \text{ does not exist} \end{cases}$$

p – Program

x – String

Φ – Universal Computer

Normalized compression distance (NCD) [4]

$$NCD_{xy} = \frac{C_{xy} - min\{C_x, C_y\}}{max\{C_x, C_y\}}$$

C_x – Length, in bits, of the compressed bzip2 for string x

C_{xy} – Length, in bits, of the compressed bzip2 for strings xy

Dataset

We analyzed a dataset composed of 30-minutes traces of RR intervals and respiration signals, acquired in the first two days of life, for 33 neonates with GA between 27 and 41 weeks.

Of these 33 neonates:

- 22 babies were premature (<37 weeks)
- 4 babies were considered extremely premature (<28 weeks)

The Pearson correlation was computed to assess the association between complexity measures and GA.

Results

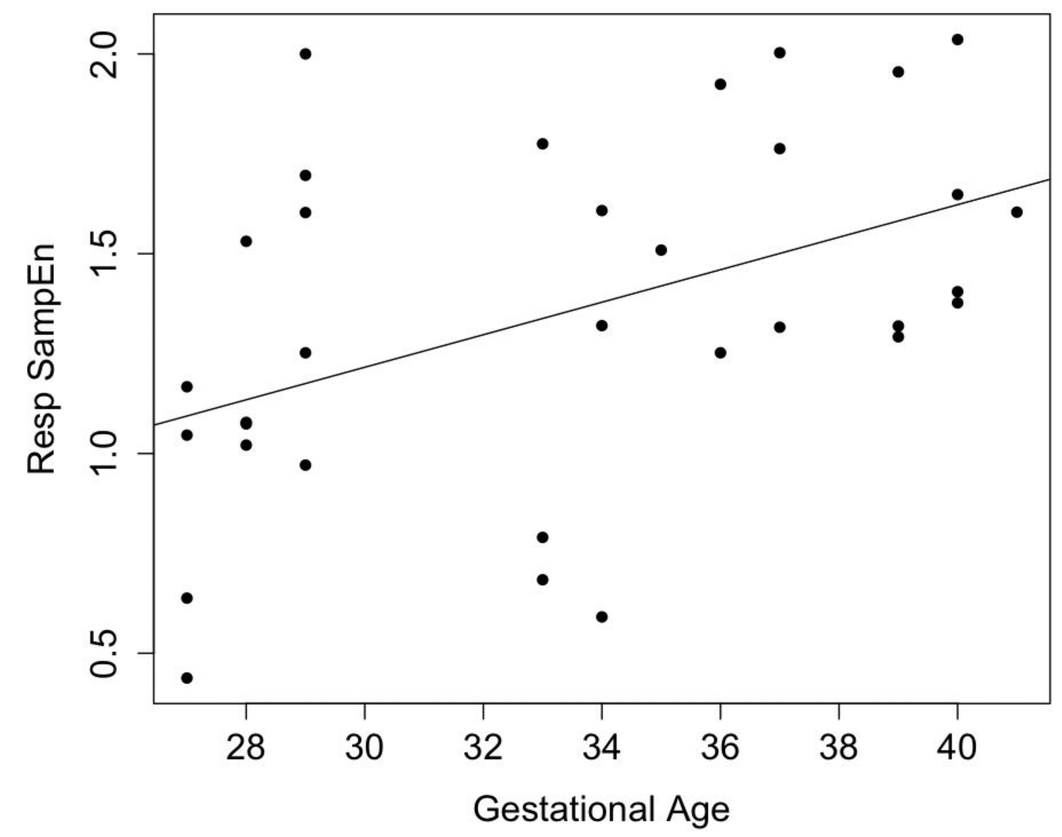

Figure 1. Respiration with **SampEn** increases as GA (r=0.46, p=0.008).

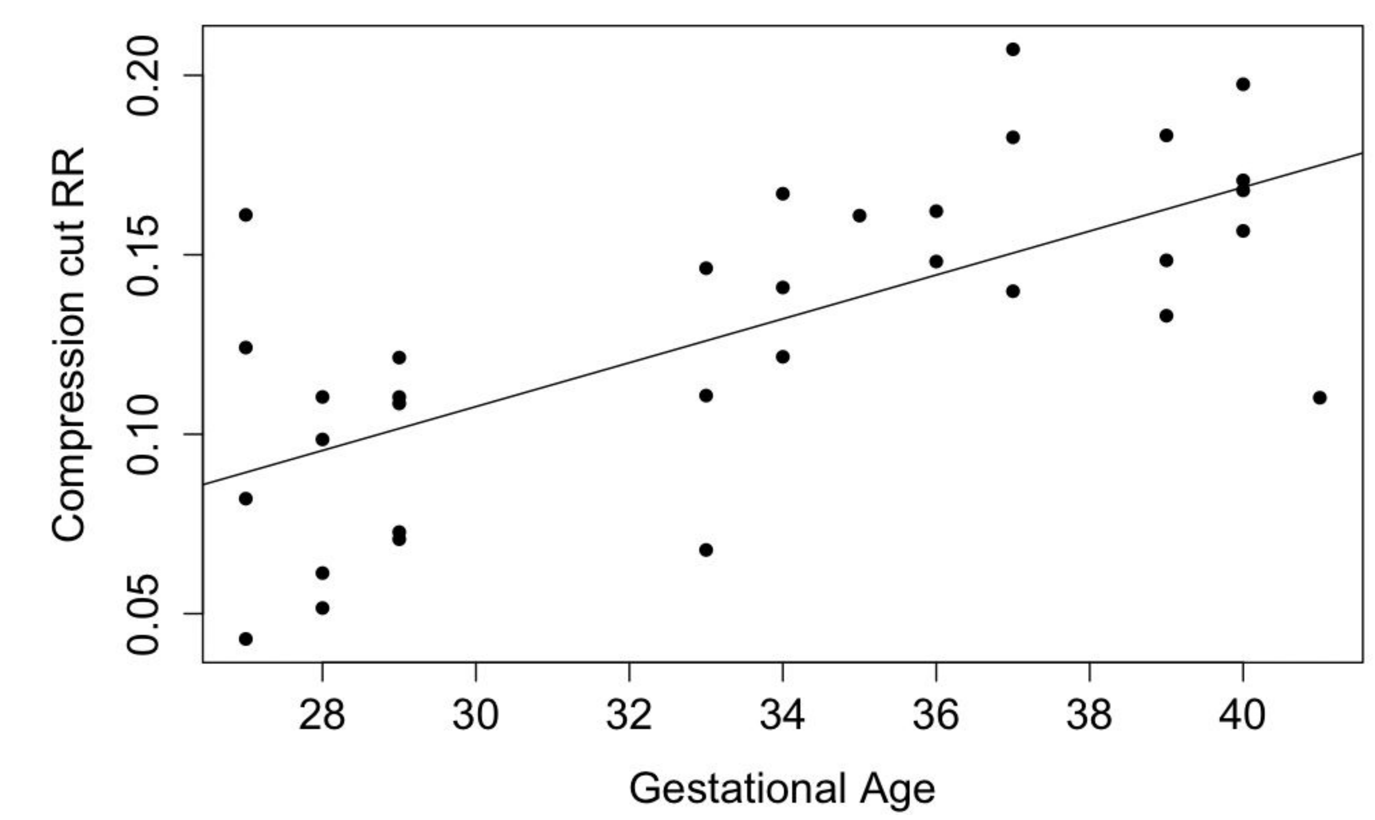

Figure 2. RR signals with **bzip2**: positive correlation with GA (r=0.69, p<0.001).

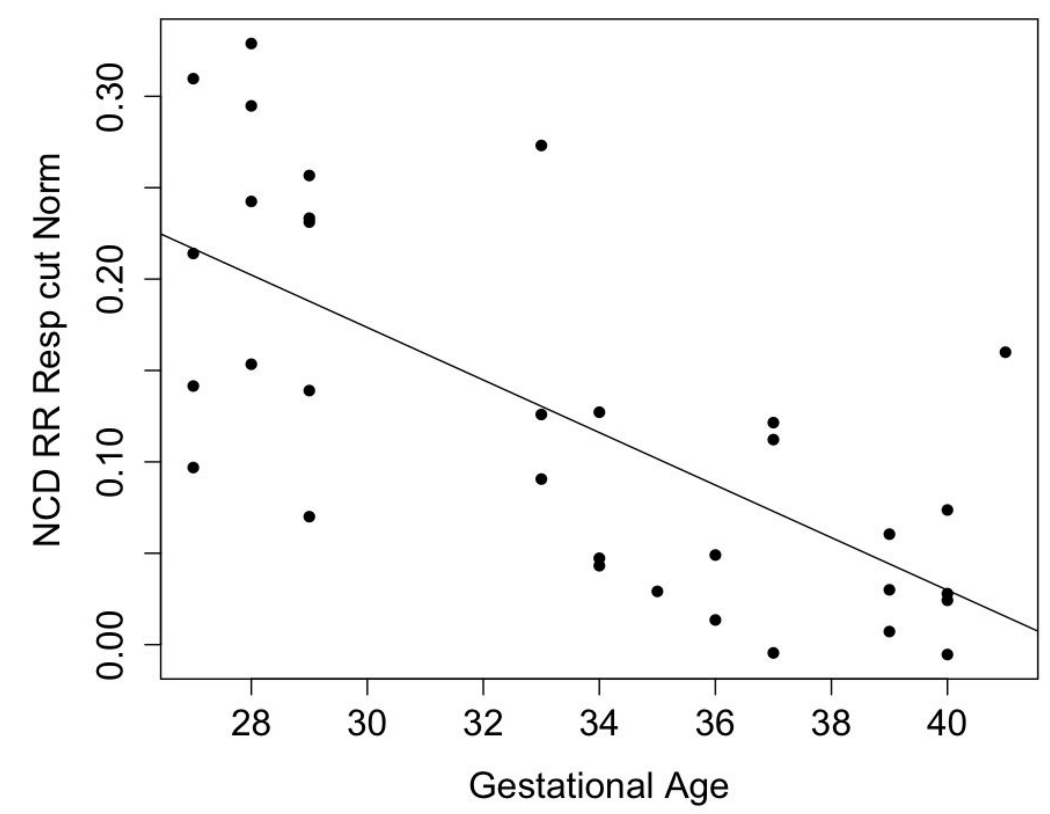

Figure 3. Complexity of **cardiorespiratory coupling** with **NCD**: a negative correlation with GA (r=-0.74, p<0.001).

Results obtained show that for the respiratory signals, SampEn increases as GA increases (see Figure 1). However, the SampEn for RR intervals and MI gave non-significant correlations. When we applied the bzip2 compressor to the RR signals, we obtained a positive correlation with GA (see Figure 2), but there was no significant correlation between bzip2 of respiratory signals and GA. For the complexity of cardiorespiratory coupling with NCD, we obtained a negative correlation with GA (see Figure 3).

Conclusions

We infer that SampEn presents better results for respiratory signals. However, bzip2 is better when using RR signals. While the complexity of the time series increases with GA, the complexity of the coupling decreases. This finding might emerge from the fact that the heart rate is highly modulated by respiration in premature babies. Future studies should investigate the complementary of these complexity measures.

References

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