Cardiorespiratory coupling is influenced by body position and slow paced 0.1 Hz breathing in a state specific manner

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Objective: Cardiorespiratory coupling (CRC), a set of cardiac and respiratory rhythms that optimise the body oxygenation and the adaptability of the cardiorespiratory system to the external and internal environment, is represented in the linear domain by pulse/respiration quotient Qpr, the number of heartbeats per respiratory cycle1,2. Slow 0.1 Hz breathing in supine position (supin01) and active standing (stand) represent the states of maximal RRI vagal and sympathetic modulation, respectively, in physiological quiescence, while standing with 0.1 Hz breathing (stand01) is characterized by simultaneous sympathovagal enhancement.

The aim of our work was to investigate the linear CRC by Qpr in 4 states: supine position with spontaneous breathing (supin), stand, supin01 and stand01.

4. Data processing

Respiration signal was low pass filtered (14th order Chebyshev II). RRI were extracted from the ECG signal using Pick Peak tool in Origin (Microsoft, Northampton, MA, USA). Since the sample rate of the respiration signal was uniform (1000 Hz), while RRI values were sampled at unevenly spaced points (sampling frequency lower than 100 Hz) a resampling of respiration signal was performed, according to the sample points of RRI. It was done using our custom Matlab program:

$$Qpr(i) = \frac{1}{\sum_{i=0}^{n} \text{time (second) at subsequent marked signal point} - \text{time (second) for previous marked signal point}}$$

$$RRI(i1,i2) = 3 + b1(i1,i2) + b2(i1,i2)$$

First we counted integer number of whole r intervals that fell between 1 and 2. In this case there were three of them (-2, -1, -0). Then parts of the boundary r intervals that belong to (1, 2) breathing interval, as non integral parts of the Qpr, were added:

$$Qpr(i1,i2) = 3 + [b1(i1,i2) + b2(i1,i2)]$$

Finally, total (integer and decimal) value of Qpr belonging to (1, 2)-breathing interval was calculated as

$$Qpr(i1,i2) = \sum_{i=0}^{n} Qpr$$

Results:

| Parameter | Supin (mean±SD %15) | Stand (mean±SD %15) | Supin01 (mean±SD %15) | Stand01 (mean±SD %15) |
|-----------|---------------------|---------------------|-----------------------|-----------------------|
| Qpr       | 0.960±0.13          | 1.005±0.13          | 1.020±0.13            | 1.050±0.09            |
| RRI       | 1.063±0.02          | 1.003±0.03          | 1.003±0.03            | 1.030±0.02            |
| BBI       | 4.017±1.03          | 8.780±1.71          | 8.452±1.94            | 10.042±4.44           |
| Qpr       | 0.993±0.07          | 0.952±0.10          | 0.362±0.06            | 0.391±0.10            |

Table 1. Mean value and 95% C.I. of RRI, BBI and Qpr for 20 healthy subjects in four physiological states: Supine-supine position with spontaneous breathing, Stand-standing with spontaneous breathing, Supin01-supine position with 0.116 breathing, Stand01-standing with slow 0.116 breathing.

Conclusion: Our results show that linear CRC Qpr is state dependent and that it increases with the behavioral task complexity. Postural change tunes Qpr by RRI modulation, while 0.1 Hz breathing dominantly by the increase of BBI. Stand01 is characterized by concomitant reciprocal adjustment of both RRI and BBI. These data imply that Qpr regulation is "loosely" and selectively coordinated in stand and supin01("dual control") while integrated in stand01 ("unitary control")9. Analogously to nonlinear CRC, Qpr is probably operated in bottom up manner of brainstem and hierarchically higher forebrain-central autonomic networks with respect to the increment of behavioral complexity task. In 0.1 Hz breathing regimes (supin01 and stand01) Qpr has higher values compared to the respective states with spontaneous breathing (supin and stand).

These results support provocative hypothesis that Qpr might be a promising marker of cardiorespiratory ventilation-perfusion efficiency, specifically increased during slow 0.1 Hz breathing. Further research on this hypothesis is necessary.

References:
1. Mosar M et al, Biol Rhythm Res 1995;26(1):100-111.
2. Schloßmann F et al, Front Physiol 2019;10:371.
3. Matić Z et al, Front Physiol 2020;11:24.
4. Bojić T, (dissertation) Alma Mater Università di Bologna, 2003.
5. Peng CK et al. Chaos 1995, 5, 82-87.
6. Peng CK et al, Am. Biomed. Eng. 2002, 30-5, 688-692.
7. Kapidžić A et al., Respi Physiol Neurobiol 2014, 203, 51-59.
8. Feldman JL et al, Annu Rev Physiol 1988;50:593-606.
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FIGURE 1. Segment of respiratory signal (A) and ECG signal (B) in one subject, recorded simultaneously, in a supine state with spontaneous respiration, for 12s, selected from a total of 1200s registered in this condition. RRI-time interval between two adjacent R peaks of ECG, BBI-breath-to-breath interval, Qpr-number of heartbeats in one breath-to-breath interval.

Methods:

The ECG (RRI) and respiration signals were simultaneously recorded in 20 healthy human subjects in four conditions:

1. Subjects

We conducted the study protocol on 20 healthy adult human subjects (13 males, age 34 41±7) which was approved by Ethical Committee of Faculty of Medicine, University of Belgrade. Inclusion criteria: absence of any health problems and an age between 20 and 40. The exclusion criteria were subjugated to any therapy (injections, medications, etc.), a history of cardiovascular, pulmonary or any other diseases; presence of any health disorders, at the time of the assessment, pathological symptoms during the experimental procedures. For female participants an additional criterion of exclusion was the second-part of menstrual cycle. All participants were advised to refrain from food and drink about 4 hours before the experiment, not to exercise, to be healthy and alert.

2. Study protocol

The study protocol was performed under controlled laboratory conditions at the Laboratory for biogases, Institute for Biophysics, Faculty of Medicine, University of Belgrade. It was conducted in quiet, refreshing and constant temperature environment (22±2°C). Experiments were undertaken between 8 and 12 AM. All subjects were subjected to 10 minutes of relaxation in a supine position before recording. There was no restriction imposed on the air flow rate. They were also strictly instructed not to talk during the experimental procedures. The ECG (RRI) and respiration signals were simultaneously recorded in 4 conditions/sequences: supine and standing positions at spontaneous breathing rates, and in supine and standing positions with the slow paced 0.1 Hz breathing rate. Session recordings lasted for 20 minutes, with a 5 minute pause between the supine and standing position, in order to meet the criteria for cardiorespiratory complexity analysis5 and to obtain the stabilization of autonomic regulation in each state6. The sequence of these four sessions was randomly chosen. Slow breathing with a paced rhythm of 0.1 Hz was dictated on a computer webmeter www.webmetronom.com. Subjects were trained and instructed to slow breathing regime before the recording sessions.

3. Data acquisition

Cardiorespiratory signal acquisition was done by means of BispecMP101 system (Bispec System, Inc. Santa Barbara, CA, USA.Axon/Respiracell 3.01 software). Main ECG lead registration electrodes were attached on the projections of clavicle bones and the grounding on the ankle of the right leg. The belt with receive strain gauge transducer for continuous recording of breathing was placed slightly above the coastal line. Both signals were sampled with 1000 Hz frequency rate.

Data processing

Respiration signal was low pass filtered (14th order Chebyshev II). RRI were extracted from the ECG signal using Pick Peak tool.