# Relationship Between Breath Regulation and Stroke Volume with Exercise Intensity: a Pilot Study

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Presentation in eTELEMED 2020
November 21, 2020 to November 25, 2020 - Valencia, Spain

# Curriculum Vitae

## ➢Educational experience

- 2012.09 –2016.06: Department of **Information Management**, College of Management, THU
- 2016.09 –now : Institute of **Biomedical Engineering**, College of ECE, NCTU

## ➢Conference paper

- **W.-C. Lai, P.-H. Huang, and T.-C. Hsiao,**" Relationship Between Breath Regulation and Stroke Volume with Exercise Intensity: a Pilot Study," eTELEMED 2020, Valencia, Spain, Nov. 21-25, 2020.

## ➢Certificate:

- 2017/04/25 Certified LabVIEW Associate Developer (CLAD, 100-317-19067)

# Our laboratory

- **Focus on:**

## ➢Physiology

- Cardiovascular
- Respiration

Gaming, exercising, ….and so on

## ➢ Method

- Decomposition EMD/Hola
- Modeling RPLS
- Classifier XCS

Investigate Homeostasis mechanism

# Outline

## 1. Introduction

1.1 Background
- The regulation during exercise
- Circulation & respiration in human

1.2 Motivation
- Literature study

1.3 Objective

## 2. Material and Method

2.1 Experiment procedure

2.2 Equipment

2.3 Data demonstration
- Impedance cardiography
- Breathing rate

2.4 Data processing and statistic analysis

## 3. Experimental result

3.1 Participate description

3.2 Result of subject
- Corrected data
- Averaged in per stage

3.3 Comparison of HRV and SVV
- Power spectrum in per stage
- Comparison in normalized LF and HF

3.4 Statistical result

## 4. Discussion

4.1 HR, SV, and CO variations during exercising

4.2 HRV and SVV comparison during exercising

4.3 Limitation

## 5. Conclusion

## 6. Further work

# Background

“ *Sport plays a significant role as a promoter of social integration and economic development in different geographical, cultural and political contexts. Sport is a powerful tool to strengthen social ties and networks, and to promote ideals of peace, fraternity, solidarity, non-violence, tolerance and justice.*

*From a development perspective, the focus is always on mass sport and not elite sport.*”

*United Nations Office on Sport for Development and Peace, UNOSDP*

# Background

- Physical activity is defined as any bodily movement produced by skeletal muscle that requires energy expenditure [1].
- Exercise is a physical activity that is planned, structured, repetitive, and purposeful, with the purpose of achieving improvement or for one or multiple physical fitness[1].
- To promote the important exercise, the Sports Administration in Taiwan surveyed the grown of the sports population:

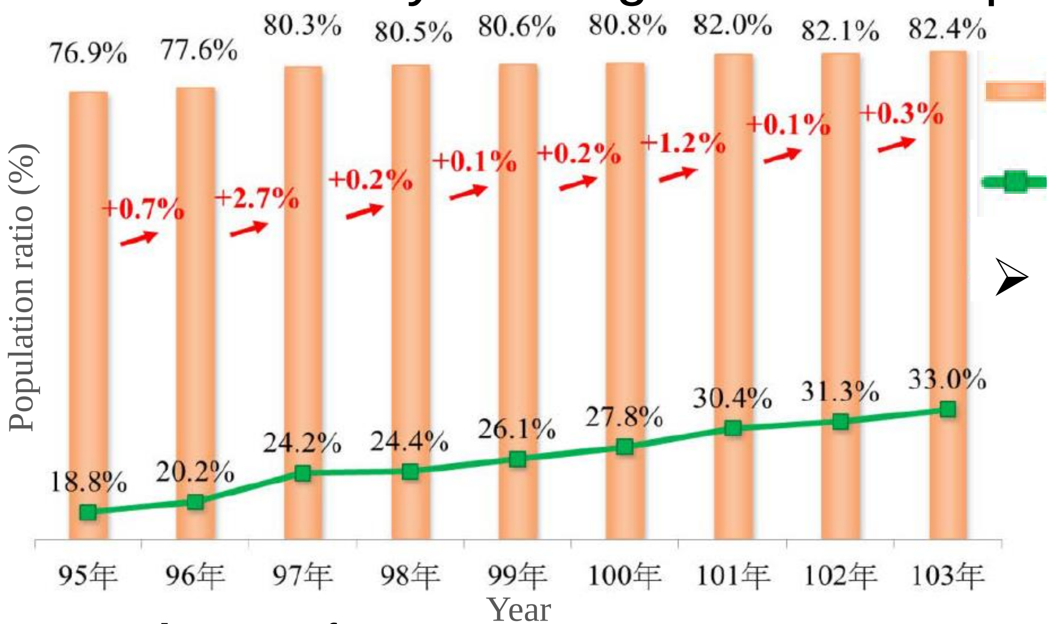



Figure 1 _The ratio of exerciser in Taiwan

(From "Sports Love Taiwan" The project from 2016 to 2021 was proposed by Sports Administration in Taiwan.)

- In 2019,
  - the proportion of exercising in Taiwan is 83.6%.
  - the proportion of regular exercise population is 33.6%[2].



[1] World health Organization (2019). Physical activity. https://www.who.int/health-topics/physical-activity#tab=tab_1

[2]教育部體育署(2019).中華民國108年運動現況調查結案報告書. https://reurl.cc/WLEkxD\中華民國108年運動現況調查結案報告書.pdf

# The cardiovascular regulation during dynamic exercise

(中華民國鐵人三項協會,2013)

- People need to take in oxygen ($O_2$) continuously during movement or exercising. In this way, the production of carbon dioxide ($CO_2$) also increases.
- To avoid a decrease in the PH value of blood, human expels CO2 from the blood in the alveoli by increasing breathing rate (BR).
  - The heart ejects the amount of blood when heartbeats.
  - The speed of the heartbeat is called heart rate (HR).
- HR can be accelerated with an increase in exercise time or exercise intensity. Athletes breathe skillfully and regulate breathing patterns.
  - Riding bicycle: the frequency of the prevailing pedal and breathing frequency per pedal cycle [3]
  - Swimming: the breathing action and swimming action [4]
  - Running: breathing rhythms and stepping [5]

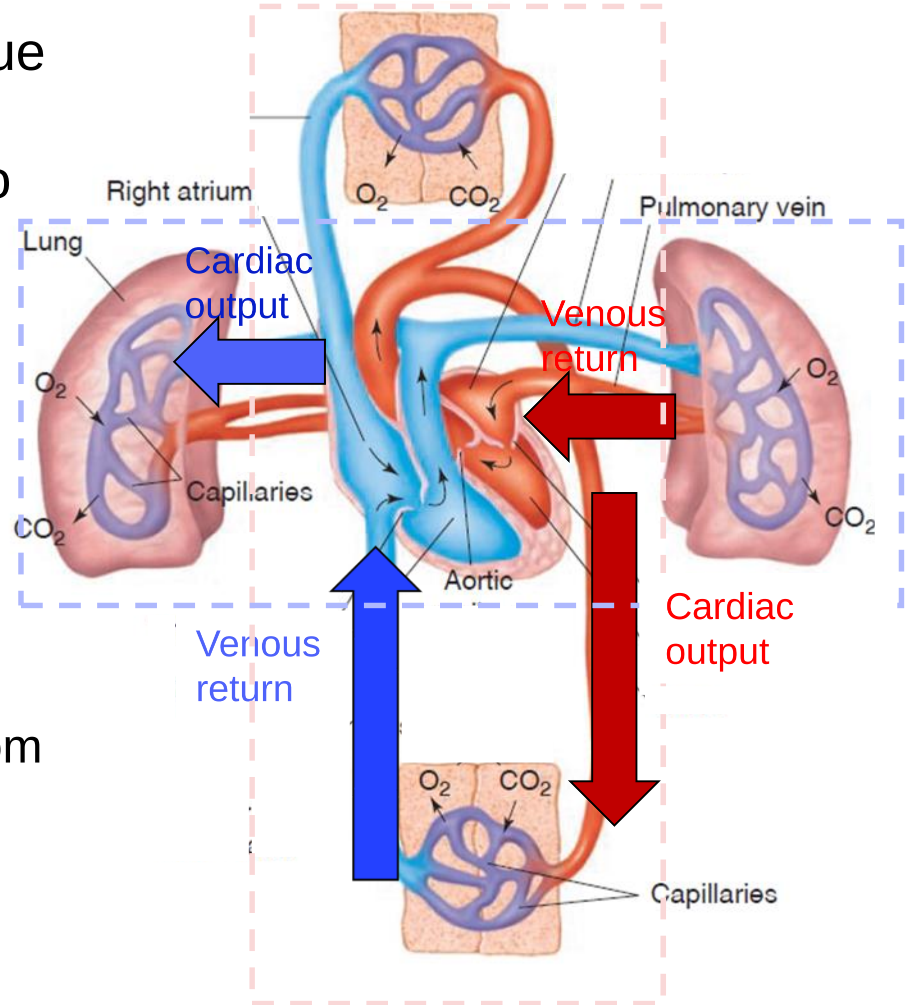
[3]Garlando, et. al., "Effect of coupling the breathing-and cycling rhythms on oxygen uptake during bicycle ergometry." *European journal of Applied Physiology and Occupational Physiology*, 54(5):497-501, 1985.

[4]Daley, et. al., "Impact loading and locomotor-respiratory coordination significantly influence breathing dynamics in running humans." *PloS one*, 8(8): e70752, 2013.

[5]Formosa, D., et. al., "Front crawl stroke-coordination and symmetry: A comparison between timing and net drag force protocols." *Journal of Sports Sciences*, 31: 759-766, 2013.

# Circulation in human

- The circulation system transport $O_2$ and nutrients to the target tissue (tissue cell) by the flow of blood, performs aerobic metabolism to produce ATP to exercise ,and brings waste and the blood with higher $CO_2$ concentration back to the heart
  - Pulmonary circulation
    - Lung → Heart
  - Systemic circulation
    - Heart → Tissue
  - Cardiac output (CO)
    - The amount of blood pumped from heart in a minute.
    - = Stroke volume (SV) × HR
  - Venous return
    - The flow of blood returned to the heart.

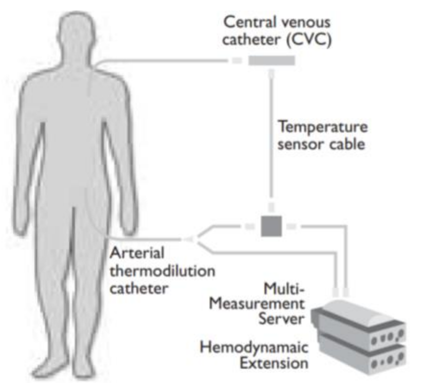



Fox., S. I. *Human physiology.* 12th ed New York: McGraw Hill, ISBN: 978-0-07-122190-0, 415, 2011

# Hemodynamic monitoring

- **CO = SV× HR**
  - The measurement of HR is relatively mature technology.
    Example: electrocardiography (ECG)
  - There are more SV measurement is developed.
    - obtain CO and HR to estimate SV
    - obtain SV and HR to estimate CO

- **How to measure cardiac output:**
  - Termodilution (invasive way)
  - Doppler principle (non-invasive way)
  - Transthoracic impedance and bioreactance analysis (non-invasive way)




**PiCCO**

IntelliVue MX800, Philips, Netherlands

(From Philips, Clinical Measurements, 2003)


**Doppler ultrasound**

Uscom 1A, Uscom, Australia

(From https://www.uscom.com.au/ )


**Impedance cardiography**

AESCULON, Osypka, Germany

(From Osypka, instructions for use, 2011)

# From CO to SV measurement

**SV measurement (Impedance)**

- **Bernstein** and **Osypka (2001)** proposed a new method for estimate SV (Electrical cardiometry) and a new instrument was proposed (AESCULON).
- **Kubicek (1966-1970)** summarized the results of the impedance method to estimate SV (the electrodes position and the estimation formula of SV), and proposed **Impedance cardiography** (**ICG**) measurement system to monitor cardiac function.
- **Nyboer (1950)** attached the electrodes on **limbs of body** and measure impedance for human and observed the impedance change would influenced by blood flow. The SV estimation was calculated by the electrodes' distance and d the deep tissues of the segment of resistance.
- **Kedrov (1949)** attached the electrodes to  tissue of animal brain and observed electrical resistance of the mass of living tissue (cat) by **electroplethysmogram**.

**CO measurement (Invasive)**

- **Ganz (1971) & Forrester (1972)** used **thermodilution (TD) by** pulmonary artery catheter to measure CO.
- **Fegler (1954)** used **thermodilution** to measure CO.
- **Hamilton (1928)** used **dye dilution method** to obtain CO measurement in **humans**.
- **Stewart (1897)** used **solution dilution method** to obtain CO measurement for **dogs**.

**Derivation**

- **Fick  (1870)** defined the calculation of oxygen uptake, and this method can be modified as the CO calculation.

1870 1948 1970

# *Literature study:*
# The bio-impedance measurement during exercise

| J.C. Denniston, et al. (1976) Measurement of cardiac output by electrical impedance at rest and during exercise | |
|---|---|
| Journal | Journal of Applied Physiology |
| Experiment procedure | ➢ Participants were studied at rest in sitting position and on a bicycle ergometer and during bicycle exercise at 300, 600, and 900. |
| Contribution | ➢ SV and CO were measured by ICG and dye dilution method.<br>➢ CO (ICG) and oxygen uptake are subjected to regression analysis, and the correlation coefficient is also greater than 0.9.<br>➢ CO value obtained by ICG under dynamic conditions has a certain accuracy. |

| Richard, et al. (2001) Non-invasive cardiac output evaluation during a maximal progressive exercise test using a new impedance cardiograph device | |
|---|---|
| Journal | European journal of applied physiology |
| Experiment procedure | ➢ Participants undergo a ramp bicycle exercise to a maximum intensity level. (increase rate 20-35 W per min) |
| Contribution | ➢ CO was measured by CO and the Fick method.<br>➢ The correlation between CO (ICG) and CO (Fick method) is r=0.94<br>➢ ICG provides a clinically acceptable evaluation of CO in healthy participant during an incremental exercise. |

*Literature study:*

# Variation in stroke volume in exercise

| P. O. Åstrand, et al. (1964) Cardiac output during submaximal and maximal work | |
|---|---|
| Journal | Journal of Applied Physiology |
| Contribution | To compare the subject, this paper set the maximum SV and maximum $O_2$ uptake of a single subject to 100%:<br>• In 40% $O_2$ uptake ,HR is 110 and the SV is close to 100%.<br>• In 100% $O_2$ uptake, HR is also increased to 200 at any time. The SV does not change much.<br>✓ The result can be inferred that more than 40% uptake, SV still maintains the maximum output, and CO increases with the increase in HR |

| T. Fujinami, et al. (1979) Impedance cardiography for the assessment of cardiac function during exercise | |
|---|---|
| Journal | Japanese circulation journal |
| Contribution | • The changes in SV was measured by ICG during exercise. |

| Chanlter, et al. (2011) Use of the Frank-Starling mechanism during exercise is linked to exercise-induced changes in arterial load | |
|---|---|
| Journal | America journal of physiology-heart and circulatory physiology |
| Contribution | During cycling, CO would increase and SV would different in different index of arterial elastance:<br>• SV would increase in 3 groups at incremental HR (from rest to 25% physical load.<br>• SV would decrease, no change , increase in 3 groups at incremental HR (from 50% exercise load to peak physical load) |

# *Literature study:*
# Assessment and comparison of ANS in HR and SV

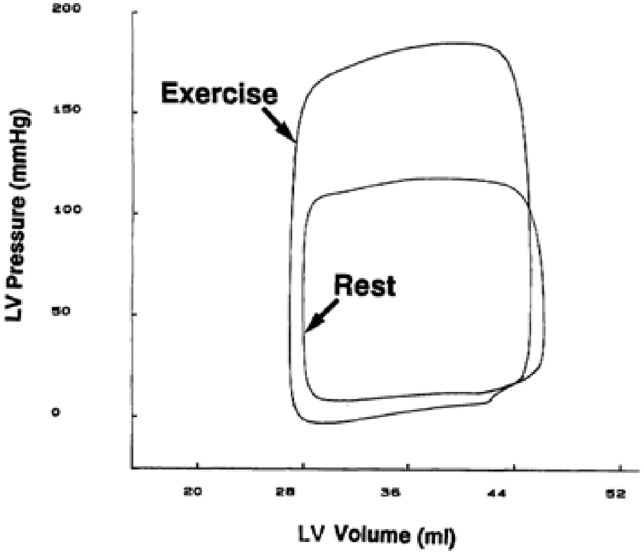
| Pichon, et al. (2004) Spectral analysis of heart rate variability during exercise in trained subjects. | | | |
|---|---|---|---|
| Journal | Medicine and science in sports and exercise | | |
| Material | 12- lead ECG and analysis breath-by-breath system | Subjects | 14 healthy cyclists |
| Contribution | Measure heart rate variability (HRV) index in exercise:<br>• high frequency and low frequency was existed in exercise<br>• Increasing exercise intensity was associated with normalized HF because of respiratory rate and decreased LF power.<br>✓ HRV index were reflected automatic nervous system (ANS). HF was associated with respiratory response and exercise intensity. | | |

| Liu, et al. (2004) Comparison of heart rate variability and stroke volume variability | | | |
|---|---|---|---|
| Journal | Autonomic neuroscience | | |
| Material | ultrasound imaging | Subjects | 12 males |
| Contribution | Stroke volume variability (SVV) used the same analysis method of HRV.<br>• A LF peak around 0.1 Hz and a HF peak around 0.3 Hz were as clearly observed in the SVV spectrum as in the HRV spectrum.<br>• The LF/HF ratio in SVV was significantly lower than that in HRV.<br>✓ SVV provides different information about the activity of the ANS than HRV. | | |

# Objective

✓ CO=HR*SV would increase at exercise.
✓ HR and SV were varied exercise loading
⇒ being an index of the cardiac function and the neuron activity diagnosis.

Figure_ The left ventricular pressure-volume loops at rest and exercise.




Cheng, Che-Ping, Yuichiro Igarashi, and William C. Little, "Mechanism of augmented rate of left ventricular filling during exercise." Circulation Research, 70.1:9-19, 1992.

## Hypotheses

- SV would increased in incremental exercise load.
- The energy in the high frequency region obtained through spectrum analysis of heart rate variability will be responded to under high exercise intensity.
- The variability of SV will be different from the variability of HR under high exercise intensity.

## Objective

Design the incremental experiment, and

- confirm the different variations in CO, SV, and HR during exercising;
- compare the relation of HRV and SVV for investigating cardiac function and neuron activity.



# Material and Method

*Material and Method:*

# Experimental procedure

This study was approved by the REC of NCTU (no. 107-092).

## ➢ Procedure

Baseline (3 mins) → Riding (3 mins) → … → Riding (3 mins) → Rest (3 mins)

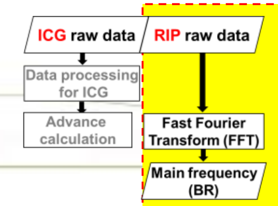
- **When riding, participant needs to**
  - ✓ maintain 60 rpm
  - ✓ increased resistance 25 watts per 3 minutes until exhaustion

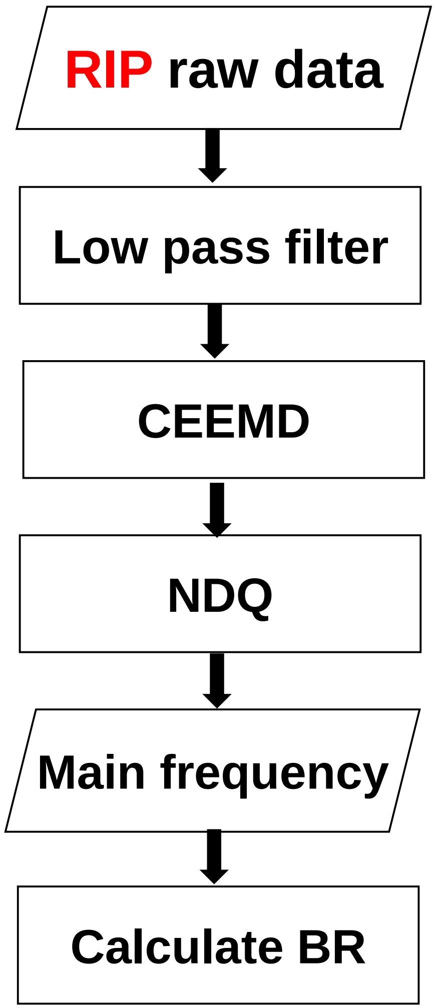
## ➢ Equipment

- **Revolutions per minute (RPM) and ergometer: Indoor bicycle**
  (Wattbike Pro, Wattbike, UK)
- **Breathing signal: Respiratory inductance plethysmography (RIP)**
  (Ambu Sleepmate Ripmate Inductance Belt Thorax, Ambu INC., USA)
- **Stroke volume and heart rate: Impedance cardiography (ICG)**
  (AESCULON, Osypka, Germany)
- **Computer**
  (TravelMate –P243 –M in intel Pentium B980, Acer, Taiwan
  and Asus X550v in Intel® Core™ i7-6700HQ, Asus, Taiwan)

➢ **Exercise habit and basic physiological information (height, weight, and years) would be investigated before experiment.**

# Data processing procedure




- BR would be calculated in each stages.
  - Sample rate: 200 samples per second
  - Example: exercising (3 minutes)

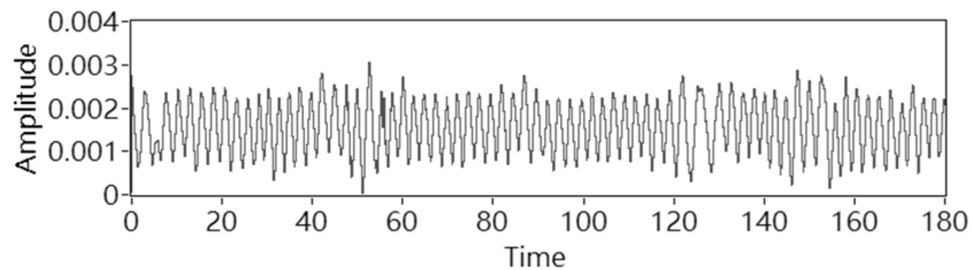
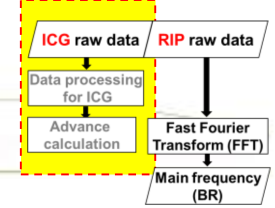


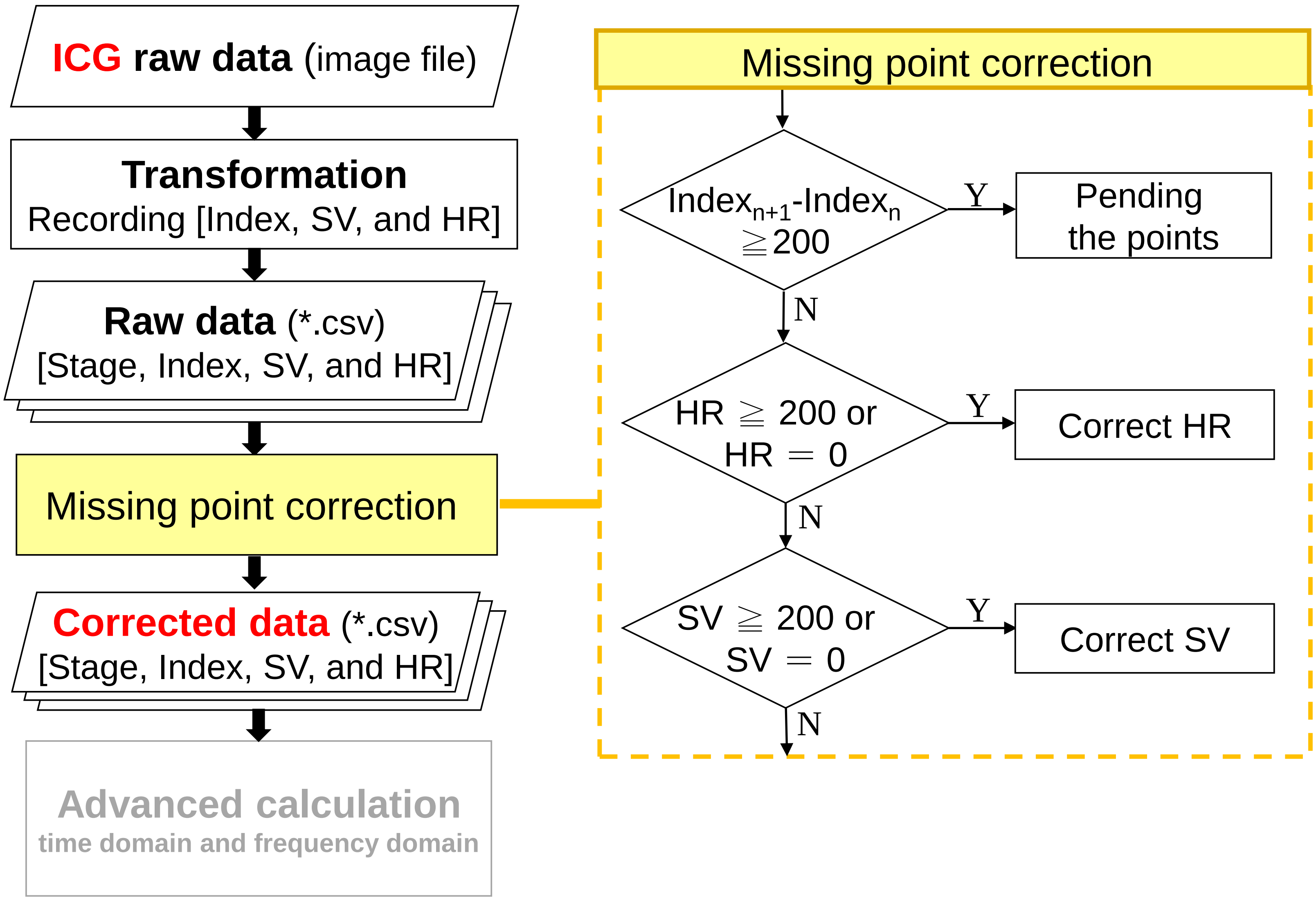

Figure. Data demonstration of RIP signal during exercise

- The thoracic movement or abdomen movement was observed by the oscillation of RIP signal.
- CEEMD was used for filtering.
  - ✓ Find main component and calculate breathing rate.

*Material and Method:*

# Data processing for ICG

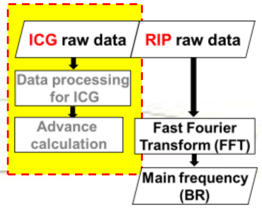


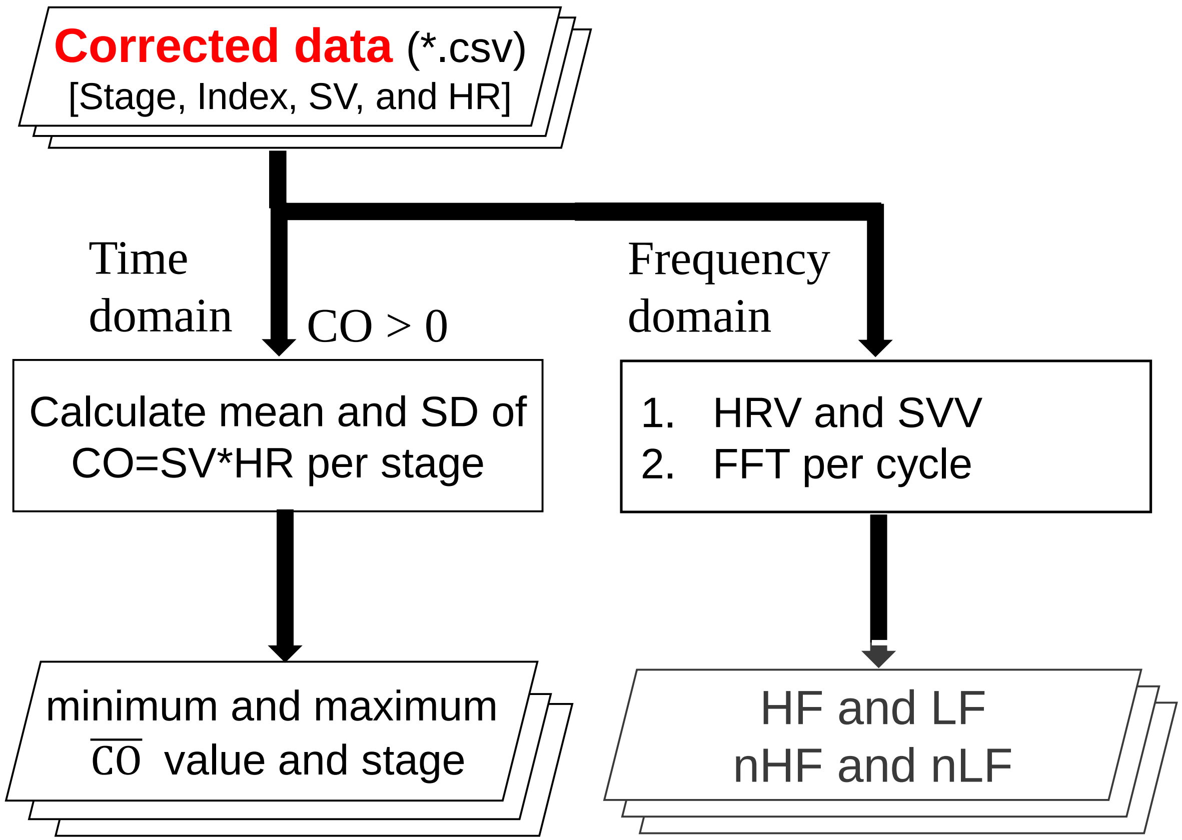



*Material and Method:*

# Advanced calculation

$\overline{CO}_i$: mean of CO in $i^{th}$ stage
$\overline{CO}_{max}$: maximum value of $\overline{CO}_i$

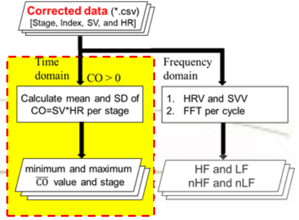



- LF: 0.04~0.15 Hz
- HF: 0.15~0.40 Hz
- nLF: LF/(LF+HF)
- nHF: HF/(LF+HF)

# *Result:*

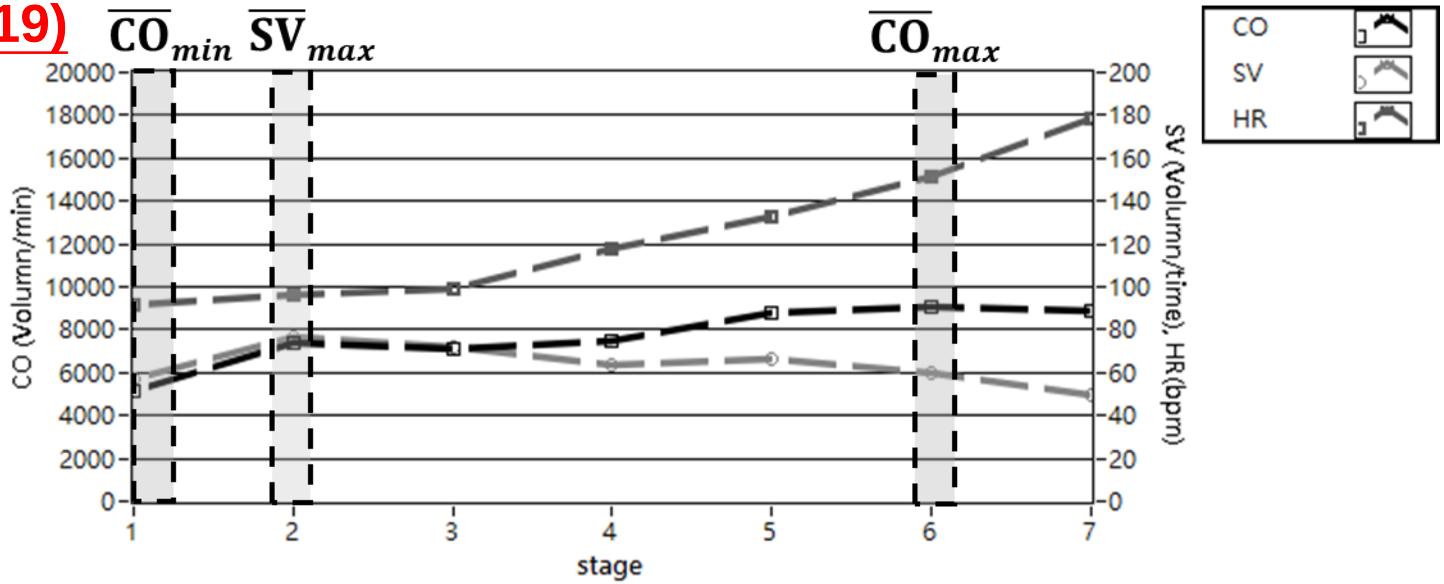
## Result of one subject (average)




- The subject information:

  Sex: Male；Height:168 cm；Weight: 66 kg

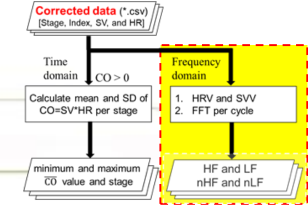
**(Subject #19)**



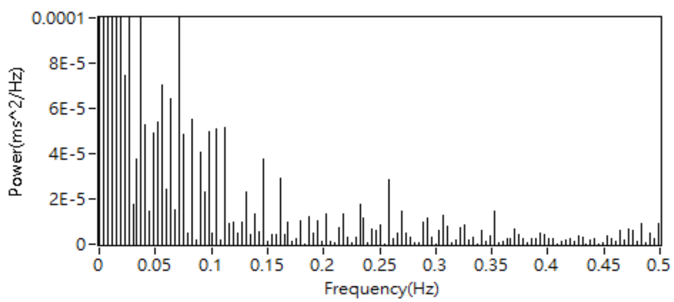
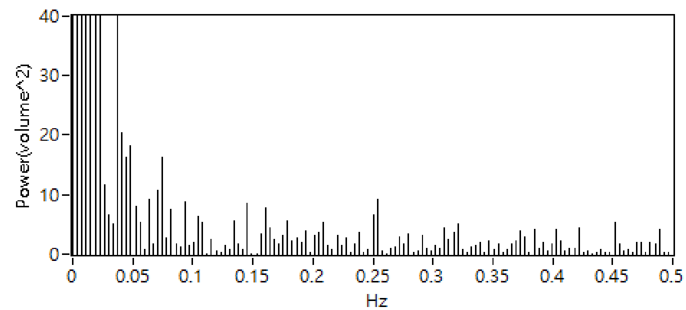
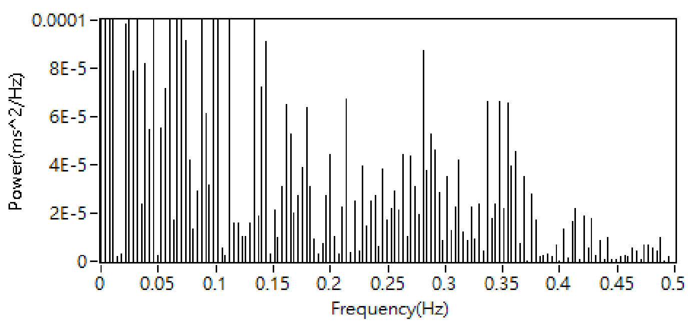
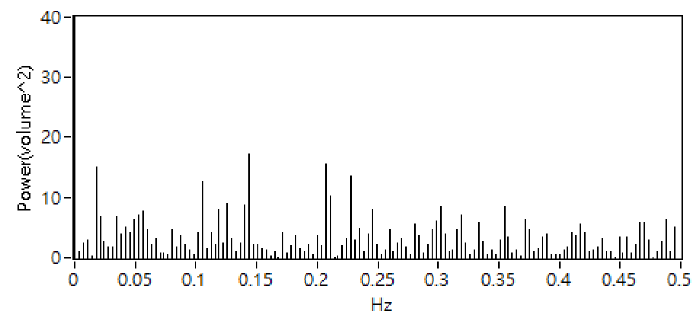
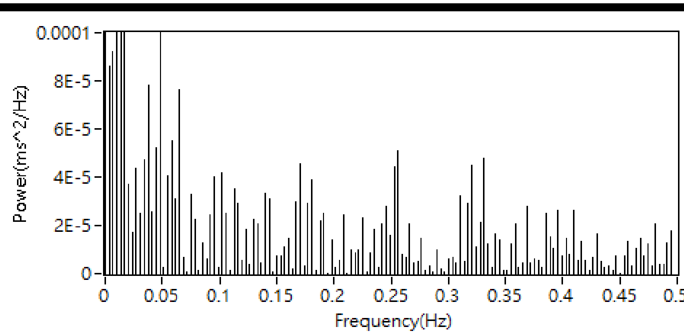
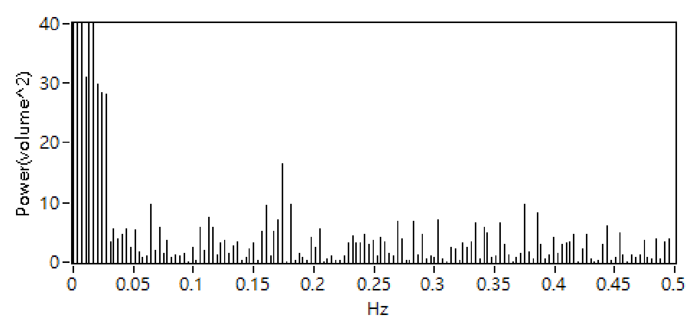

- To solve missing data, the first stage was redefined to $\overline{CO}_{min}$ , and the final stage was redefined to $\overline{CO}_{max}$.
  - During exercise, HR and CO would increase in incremental workload.
  - SV would increase at first and second stage and decline from third to last workload.
  - Although SV decreases, CO decreases in last stage of experiment.

*Result:*

# Comparison of HRV and SVV in each stage

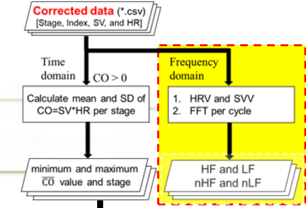



## (Subject #19)

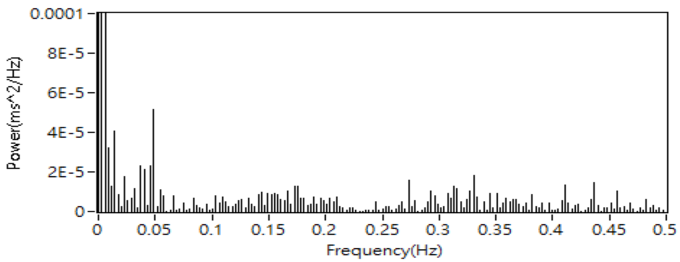
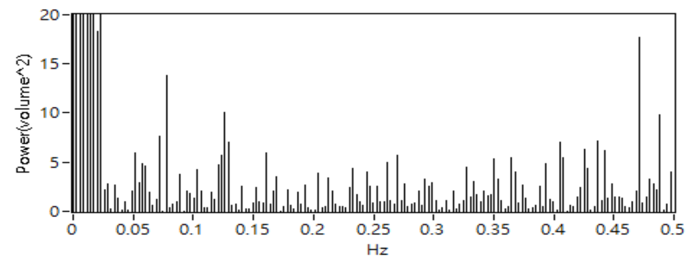
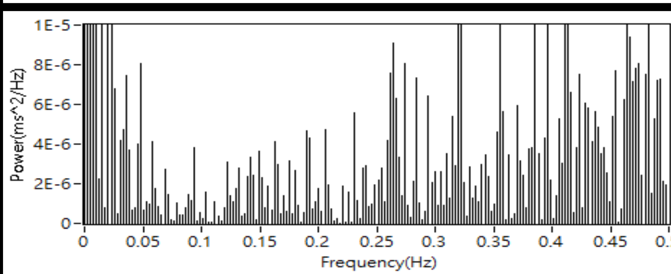
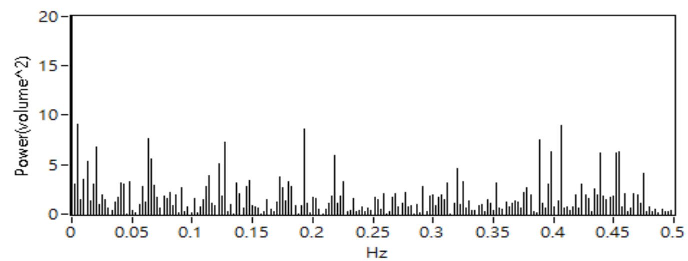
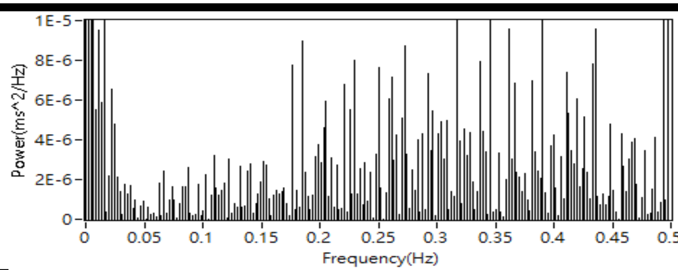
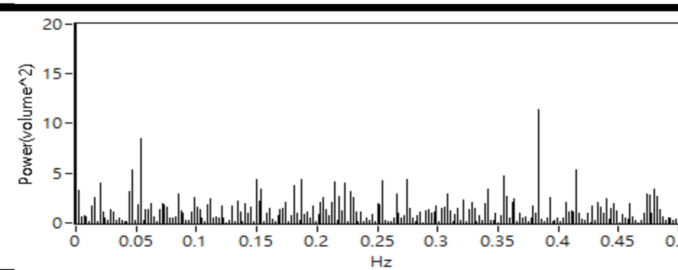
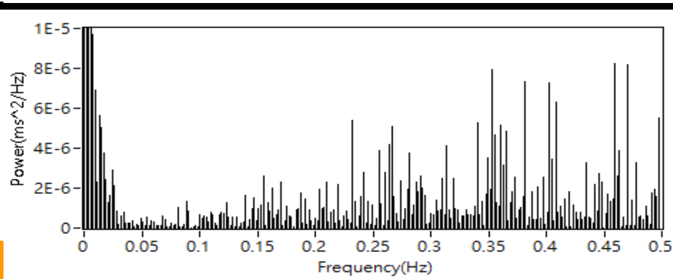
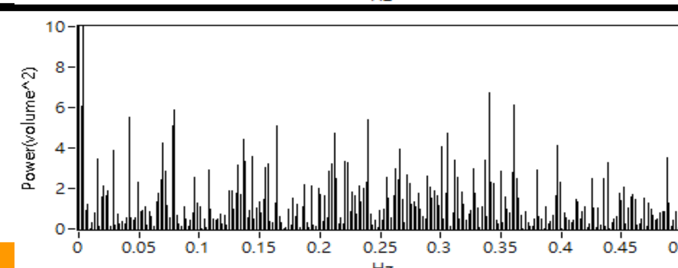
| Stage | HRV | SVV | BR (minute) |
|---|---|---|---|
| 1 |   |   | 26 |
| 2 |   |   | 28 |
| 3 |   |   | 29 |

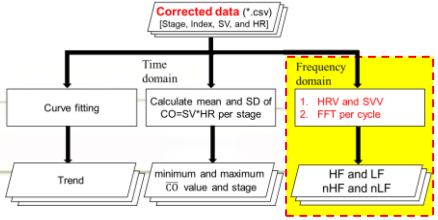
*Result:*

# Comparison of HRV and SVV in each stage



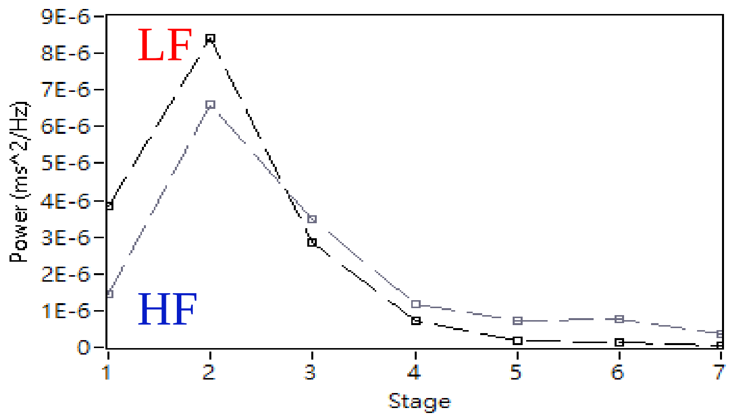
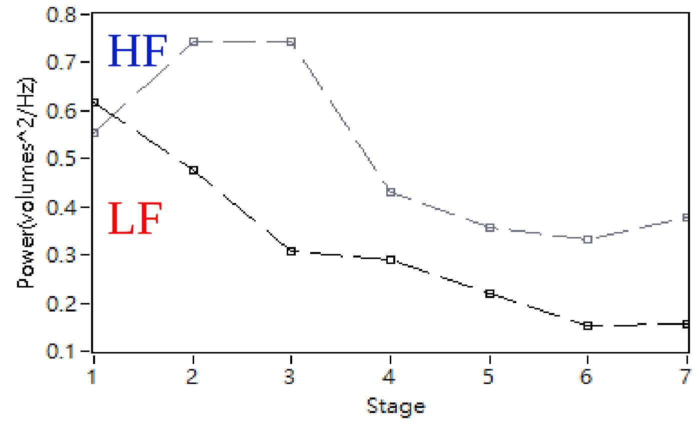
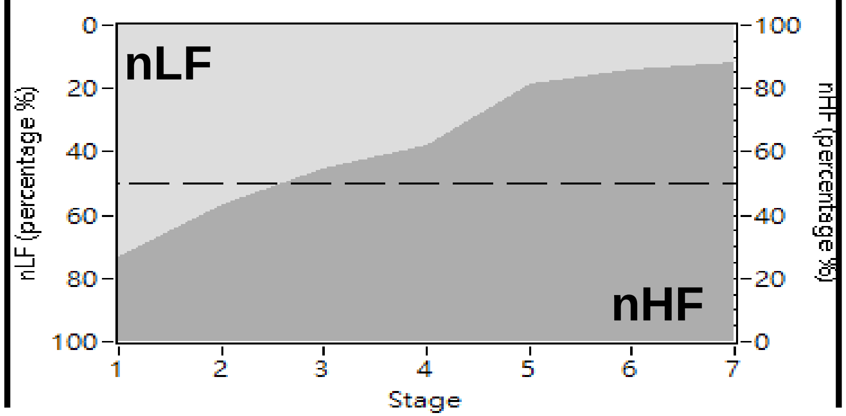
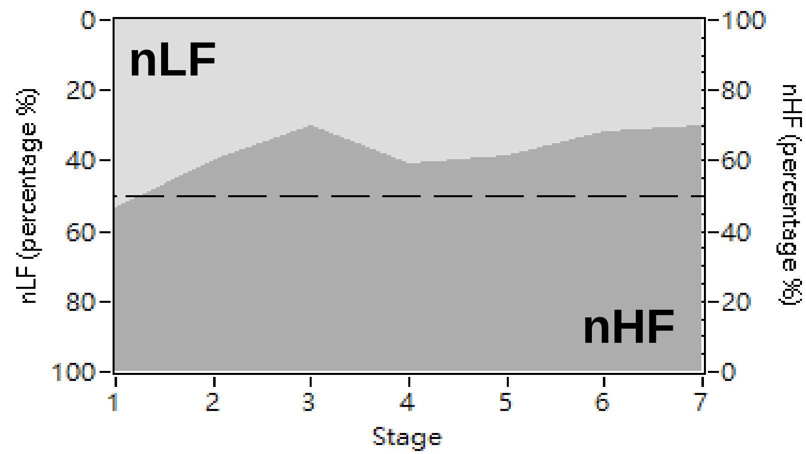

**(Subject #19)**

| Stage | HRV | SVV | BR (minute) |
|---|---|---|---|
| 4 |  |  | 33 |
| 5 |  |  | 31 |
| 6 |  |  | 32 |
| 7 |  |  | 41 |



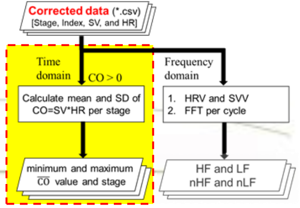

# *Result:*
# HRV and SVV in one subject

**(Subject #19)**

| | HRV | SVV |
|---|---|---|
| **LF / HF** |  |  |
| **nLF / nHF** |  |  |

# *Result:*

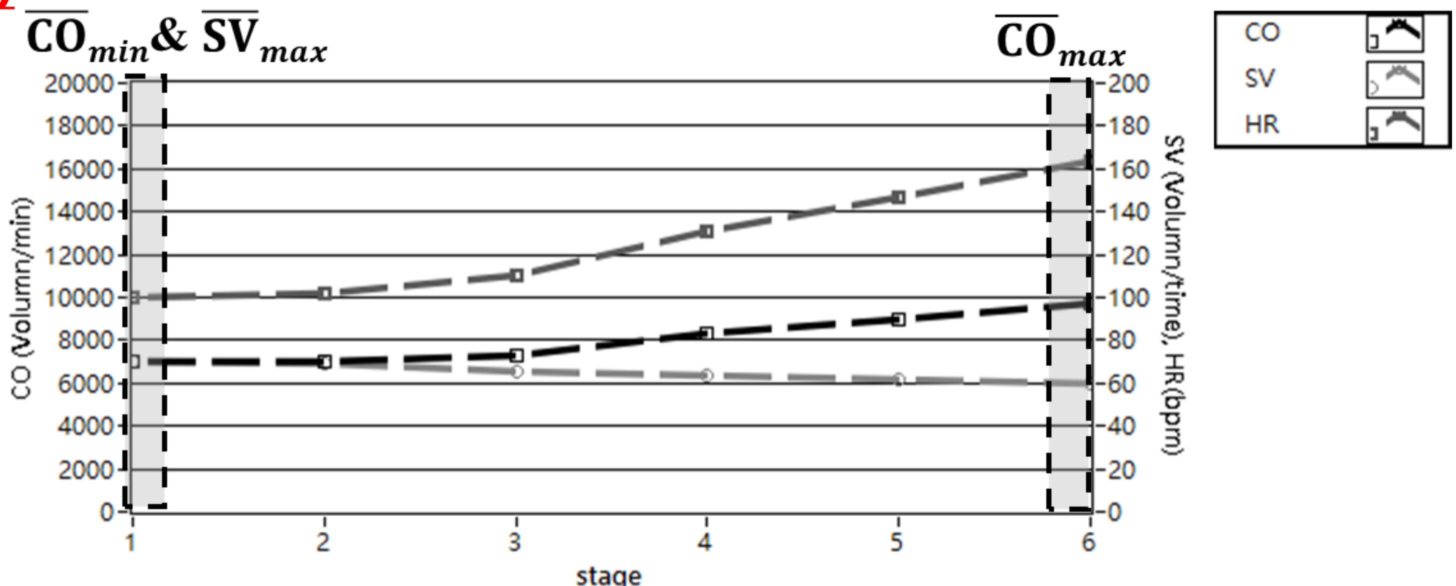
# Result of one subject (average)




- The subject information:

  Sex: Female；Height:153 cm；Weight: 58 kg

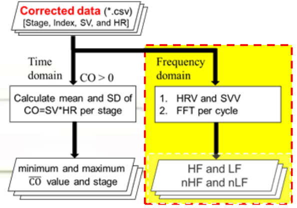
**(Subject #21)**



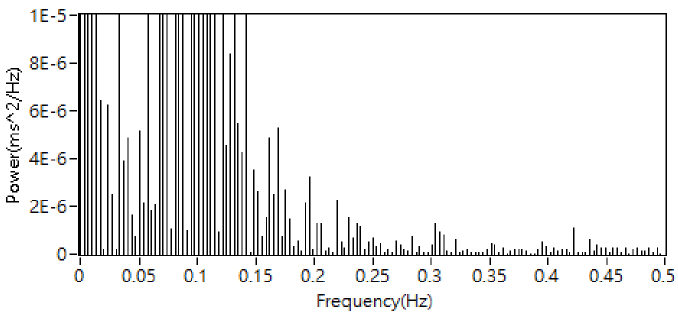
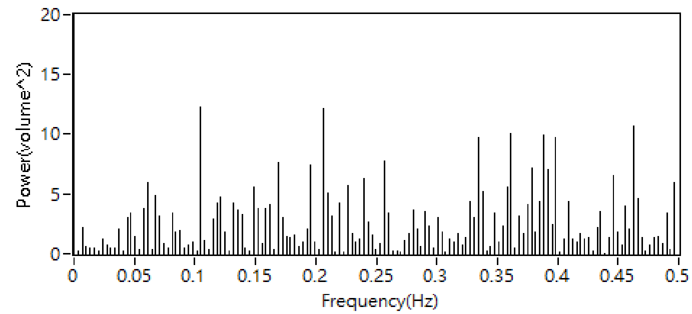
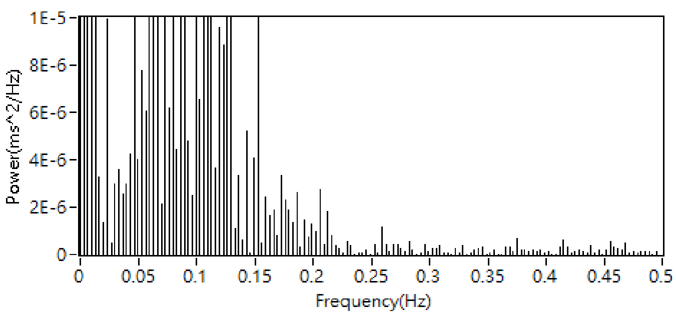
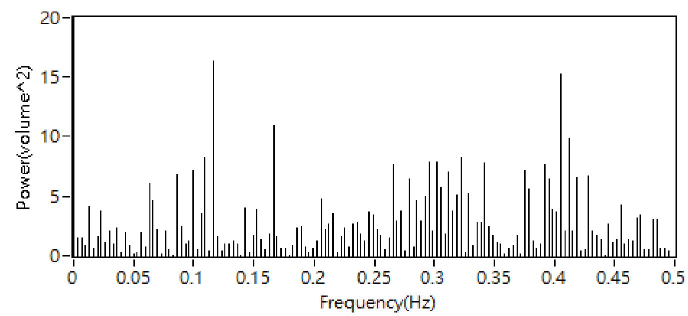
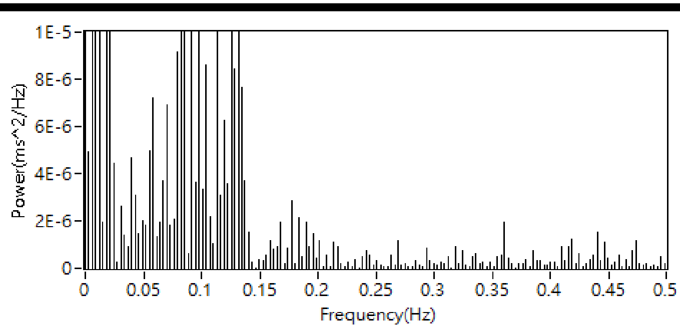
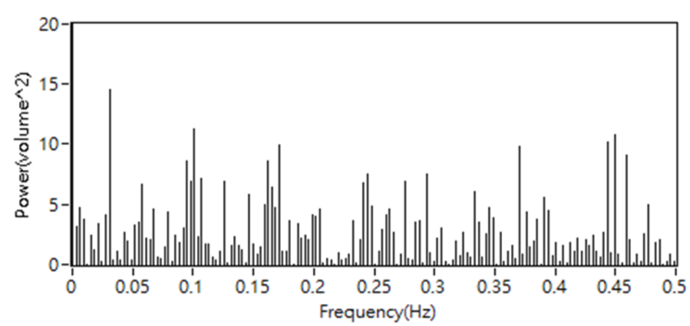

- To solve missing data, the first stage was redefined to $\overline{CO}_{min}$ , and the final stage was redefined to $\overline{CO}_{max}$.
  - During exercise, HR and CO would increase in incremental workload.
  - SV would decline from first to last workload.
  - Although SV decreases, CO still increases. (The increase in HR is greater than the decrease in SV.)

*Result:*

# Comparison of HRV and SVV in each stage

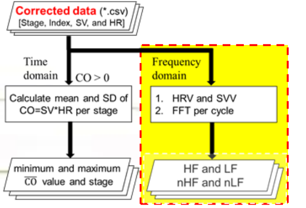



**(Subject #21)**

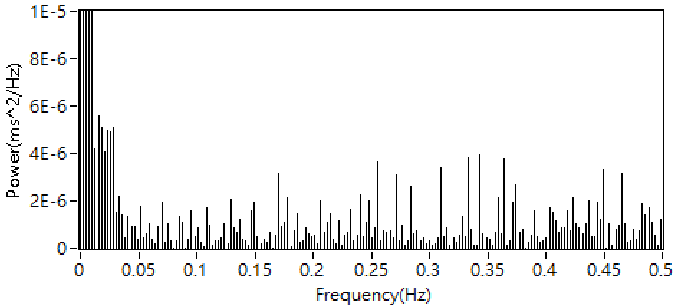
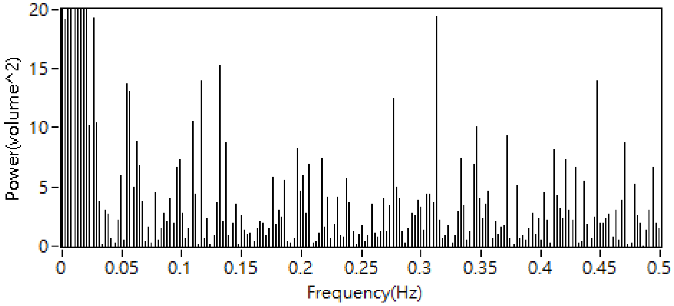
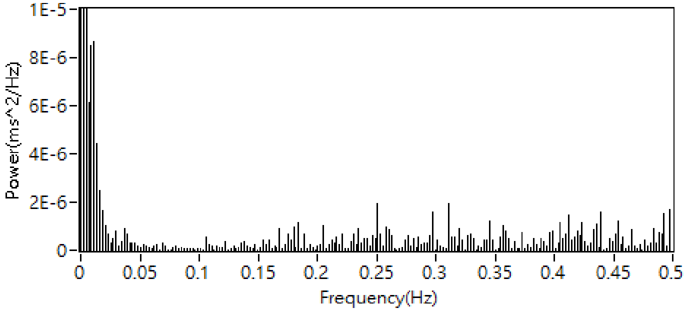
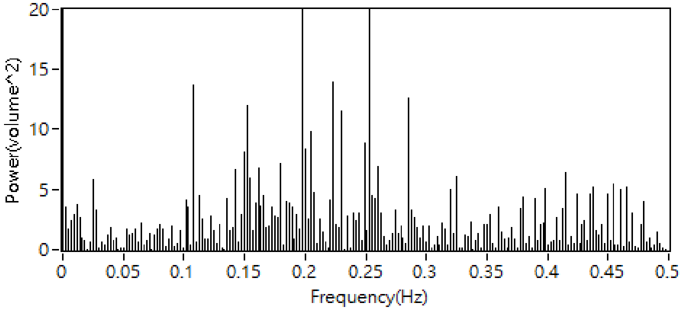
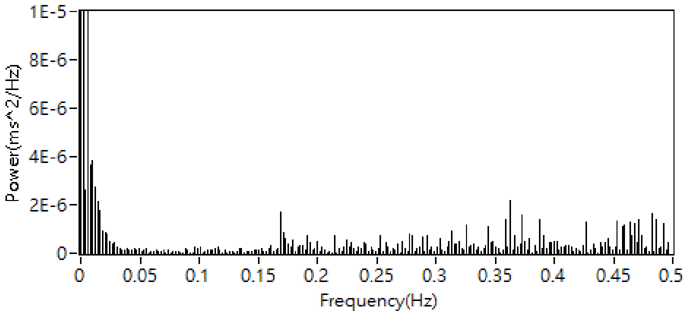
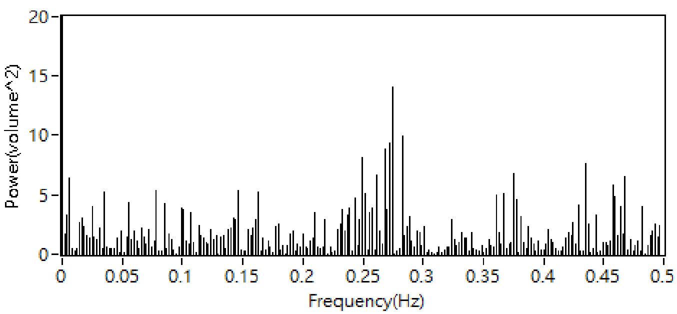
| Stage | HRV | SVV | BR (minute) |
|---|---|---|---|
| 1 |  |  | 10 |
| 2 |  |  | 10 |
| 3 |  |  | 14 |

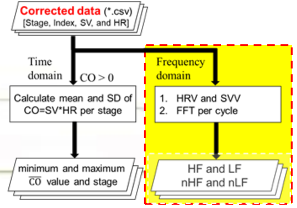
*Result:*

# Comparison of HRV and SVV in each stage



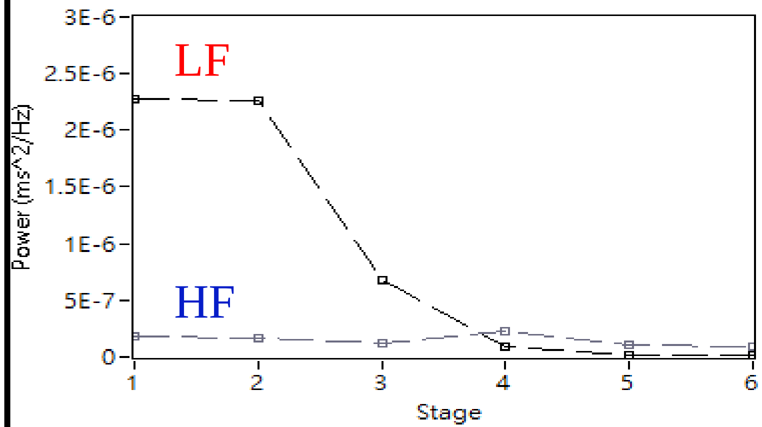
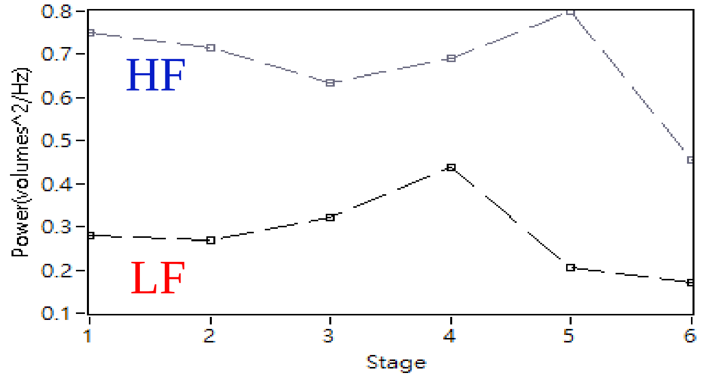
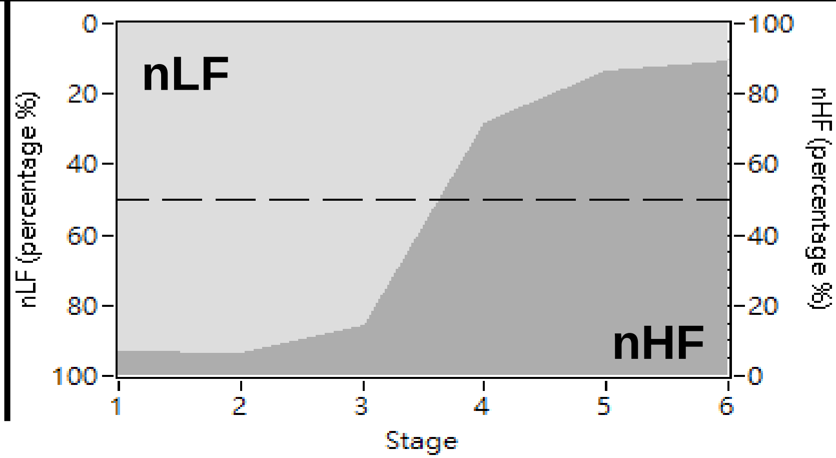
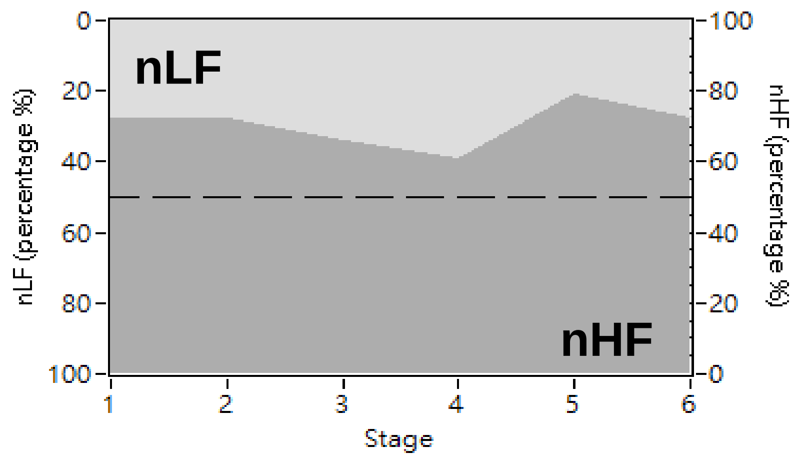

## (Subject #21)

| Stage | HRV | SVV | BR (minute) |
|---|---|---|---|
| 4 |   |   | 22 |
| 5 |   |   | 29 |
| 6 |   |   | 28 |




# *Result:*
# HRV and SVV in one subject

**(Subject #19)**

| | HRV | SVV |
|---|---|---|
| **LF / HF** |  |  |
| **nLF / nHF** |  |  |

# Discussion

# HR, SV, and CO variations during exercising

- In 1964, Astrand pointed out the HR, SV, and CO would increase during incremental exercising. The results also showed that the SV would reach to a maximal value with above 110 heart beat (1.83 Hz) in the 40% of maximal oxygen uptake.
- In this study, the results indicate

| Stage | Mean stage | $\overline{HR}$ (bpm) | $\overline{SV}$ (ml) | $\overline{CO}$(ml/minute) |
|---|---|---|---|---|
| **Rest** | **0** | 81.33 ± 12.33 | 71.69 ± 0.64 | 5827.31 ± 855.61 |
| $\overline{CO}_{min}$ | **2** | 108.36 ± 20.17 | 66.81 ± 17.89 | 7042.71 ± 1563.64 |
| $\overline{SV}_{max}$ | **3** | 115.47 ± 19.52 | 78.41 ± 15.97 | 9016.79 ± 2319.89 |
| $\overline{CO}_{max}$ | **6** | 149.00 ± 15.64 | 70.38 ± 15.64 | 10434.71 ± 2316.15 |

- ✓ Individuals reached the plateau (the stage of maximal SV value) around 3$^{rd}$ stage, saying in 75 watts working load. It could be estimated that maximal oxygen updates are around the 7$^{th}$ stage, saying in 175 watts working load.
- ✓ Except of SV, the HR and CO are increased 40.64 bpm and 3392 ml(min) at the end of maximum CO.

# HRV and SVV comparison during exercising

- In 2004, Liu pointed out the SVV can be used the HRV analysis method. The results showed that a LF peak around 0.1 Hz and a HF peak around 0.3 Hz were as clearly observed in the SVV spectrum as in the HRV spectrum. As well, the LF/HF ratio in SVV was significantly lower than that in HRV.
- In this study, the results indicate

  The LF/HF ratio in SVV was significantly lower than that in HRV, but in the stage of $\overline{\mathbf{CO}}_{max}$ , the LF/HF ratio in SVV was higher than that in HRV.

| Stage | Mean stage | LF/HF (HRV) | LF/HF (SVV) |
|---|---|---|---|
| **Rest** | **0** | 3.54 ± 2.99 | 0.40 ± 0.04 |
| $\overline{\mathbf{CO}}_{min}$ | **2** | 2.47 ± 2.82 | 0.55 ± 0.28 |
| $\overline{\mathbf{SV}}_{max}$ | **3** | 1.81 ± 2.56 | 0.46 ± 0.18 |
| $\overline{\mathbf{CO}}_{max}$ | **6** | 0.44 ± 0.63 | 0.48 ± 0.19 |

- ✓ Before stage of maximal SV
  - LF/HF ratio in SVV was lower than that in HRV.
- ✓ Between stages of maximal SV and maximal CO,
  - LF/HF ratio in SVV was higher than that in HRV.
  - HF power in HRV was greater than LF power in HRV.

# Limitation

- Participants did the incremental test by riding on the cycle ergometer, also running on the treadmill was used in other incremental tests.
- In this experiment,
  - The temperature in this experimental environment was controlled in 20℃.
  - Participants rode the cycle ergometer in the upright position.
  - The measurement of SV by impedance would be sensitive to motion. The missing data was generated by the motion artifact. The missing data will be processed (pending the points) before analysis.
  - The measurement of breathing signal by thoracic and abdomen movement probably had missing data because of 60Hz noise and unstable voltage. To solve this problem, a voltage stabilizer is used to provide a stable 110V current for the power supply.

# Conclusion

- **In this study, we performed the incremental cycling test.**
  - Individuals' SV reached the plateau and declined during incremental cycling test.
  - HR, CO and BR increased during incremental cycling test.

  - The nHF in HRV was greater than nLF in HRV in the $\overline{\mathrm{CO}}_{max}$ stage and the nHF in HRV increased significantly with high physical load.
  - The variability of SV was different from the variability of HR in per stage.
  - The nHF in HRV increased during incremental cycling exercise.

# Future works

- In the participant's selection, the participants need to have experience in related training in exercise.
- For the parameter’s record, the power of riding needs to be recorded instantaneously in exercise and investigated the responses in the cardiovascular system and the respiration system.

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***Thanks for listening***