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

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***Abstract*—Exercise is a physical activity that can enhance or maintain physical ability and health. For oxygen extraction, the ventilation will be affected by the breathing response. Cardiac Output (CO) amounts to blood by the heart pumping through the circulatory system. This blood ensures that oxygen is delivered to active tissue. During inspiration or expiration, Stroke Volume (SV) also changes. As we can see, the cardiopulmonary reactions during exercise face dynamic changes. In this work, we used a non-invasive method to measure SV and Breathing Frequency (BF) in order to investigate cardiopulmonary interactions observed during incremental exercising. The result in this experiment showed that SV would decrease to a stable value in the last stage of exercise. CO and BF would increase. SV and BF have opposite changes during incremental exercise. To the best of our knowledge, this study is the first one to use non-invasive methods to observe the changes in hemodynamic parameters during incremental exercising. The benefit of a non-invasive approach is that it is more suitable for home activities.**

Keywords- Breath Frequency; Stroke Volume; Incremental Test

I. INTRODUCTION

Physical activity helps people maintain health and physical ability. During exercise, the first observed response is breathing and heart rate. People regulate their breathing frequency and the depth of breathing unconsciously or consciously. Breathing is influenced by the rhythm of exercising. For example, athletes have their own rhythm of breathing to maintain during exercising [1]. Athletes' ability to integrate the breathing action effectively without disturbing performance is crucial to getting a better performance [2]. However, breathing patterns change dynamically during exercising.

For oxygen extraction, the ventilation is influenced by the breathing response [3]. CO amounts to blood by the heart-pumping thorough the circulatory system. The blood delivers oxygen to active tissue. The heart and lungs are in the intrathoracic space, and the gas exchanges the volume and pressure when humans exercise [3]. During expiration, the pressure increases in the chest, helping to drain off blood in the ventricle and increasing SV temporarily. On the other hand, during inspiration, the negative intrathoracic pressure makes the blood drain difficultly and decrease blood volume in the ventricle [3]. To transport blood to limbs and return to the heart, the skeletal muscle support venous return during exercising [4]. Therefore, the cardiovascular and respiratory systems are integrated during exercising. Furthermore, the responses interact in circulation during dynamic exercising.

Regulation of breathing can provide support during cycling when the BF cooperates with the frequency of pedaling. The BF increases at perceived resistance at a high level. Humans also maintain exercising continuously. According to the previous study, breathing patterns and CO are helpful for understanding mechanisms during exercising. Breathing can affect HR and SV. By inspiration and expiration, the gas pressure changes the SV volume. However, to the best of our knowledge, few papers discuss SV and BF during exercising. In this study, we aim to observe CO, SV, and HR during exercising. We also observe the breathing frequency and SV situation during exercising.

The rest of the paper is structured as follows. Section II presents the materials and the method used. Section III presents the results, and Section IV the discussion. We conclude in Section V.

II. MATERIALS AND METHOD

A. Ethical approval and Participants

This study was reviewed and approved by the Research Ethics Committee for Human Subject Protection, National Chiao Tung University (NCTU-REC-107-092). All participants received detailed information about the study objectives and experiment process before doing the

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experiment. All of the participants had to write an informed consent.

Two healthy participants were included in this experiment. Participants did not have any history of respiratory and cardiovascular diseases. Before the experiment, each participant had their blood pressure measured in the sitting position to make sure they could be included this experiment.

B. Equipment

The Respiratory Inductive Plethysmography (RIP) (Ambu Sleepmate Ripmate Inductance Belt Thorax, Ambu Inc., USA) is a non-invasive senor to measure Thoracic Wall Movement (TWM) and Abdominal Wall Movement (AWM) to observe the response in breathing. Two elastic belts are placed on the chest and abdomen. It is suitable for people to monitor breathing unobtrusively during exercise [5]. It can record Thoracoabdominal Movement (TAM) to observe the breathing feature, including breathing frequency.

The Impedance Cardiography (ICG) (AESCULON, Osypka, Germany) is a non-invasive way to measure hemodynamic parameters, such as stroke volume (SV) by bioimpedance [6]. ICG can provide continuous measures in blood flow. It places sensors on neck and chest. The sensor detects the electrical change and impedance change when blood passes through the vessel.

As stated above, the participants were evaluated by ICG and RIP in this experiment. We observed the situation during the experiment.

C. Experimental protocol

All participants had their blood pressure, SV and breathing signal measured during resting. After three minutes of resting, all subjects were asked to ride an upright-seated cycle ergometer. In cycling, the pedal should be maintained continuously ot 60 beats per minute (bpm). Stroke volume and breathing were recorded by ICG and RIP. The workload increased by 25 W every 3 minutes until they could not manage it any more. After finishing riding, participants were asked to cool down and rest.

D. The instantaneous breathing frequency Calculation

During exercising, the BF was in a dynamic situation. First, the TWM signal used Empirical Mode Decomposition (EMD) to decompose into many Intrinsic Mode Functions (IMFs) [7]. The algorithm of EMD is shown in Figure 1. However, the problem with EMD is that mode mixing is involved in IMFs. The Complete Ensemble Empirical Mode Decomposition (CEEMD) added a pair of white noise to the signal to solve the mode-mixing problem [8]. The algorithm of CEEMD is shown in Figure 2. After decomposing the signal, a significant test is used in this procedure to ensure a dominant component. Therefore, Normalize Direct Quadrature (NDQ) is used to decompose the dominant component [9]. NDQ is shown in Figure 3. This procedure of analysis was developed by a software platform (LabVIEW version 2018, National Instruments Corp, Austin, USA).

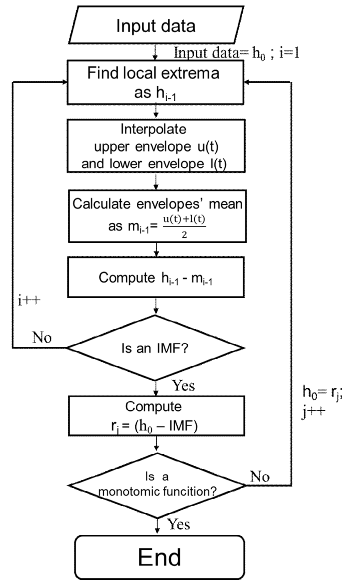

Figure 1. The algorithm of EMD

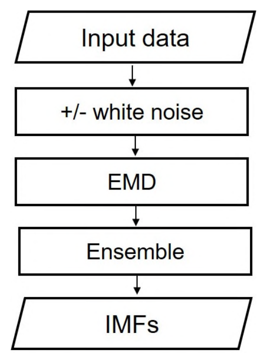

Figure 2. The algorithm of CEEMD

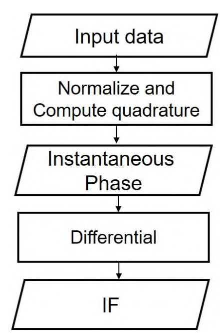

Figure 3. The algorithm of NDQ

III. RESULT

A. *Participants description*

In this experiment, participants have different riding times. Participants are one man and one woman. The participants description is shown in Table I.

TABLE I. PARTICIPATE DESCRIPTION

Sex	Male	Woman
Age	23	30
Height	168 cm	153 cm
Weight	66 kg	58 kg
Riding time	21 minutes	18 minutes

B. *The result of the experiment*

The result of the experiment is shown in Table II. The change during exercising is shown in Figures 4 to 7. In Figure 4 and Figure 5, CO increases during exercising. By contrast, SV decreases until the last stage. SV decreases in stable volume. HR increases over the exercising time. In Figure 6 and Figure 7, BF and SV had the opposite trend during exercising. In Figure 8 and Figure 9, HR and BF had the same trend during exercising.

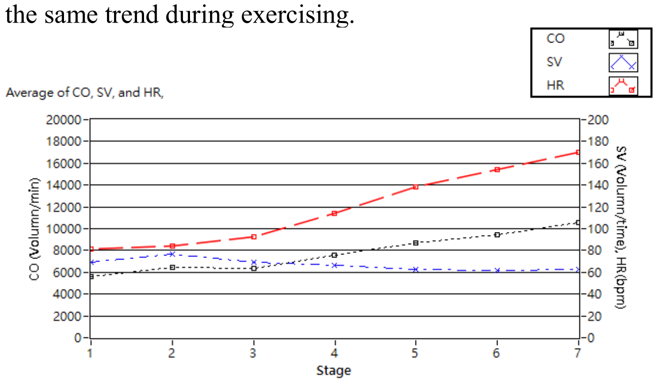

Figure 4. The CO, SV, and HR change in man

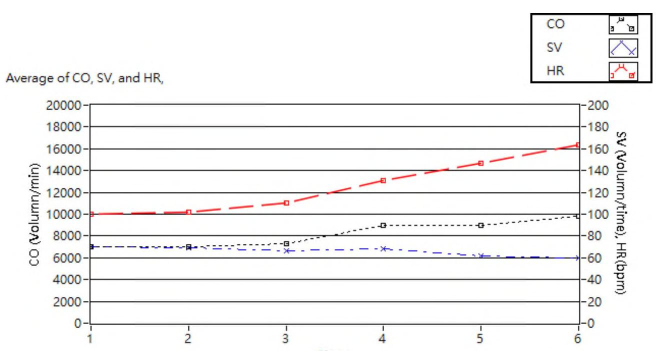

Figure 5. The CO, SV, and HR change in woman

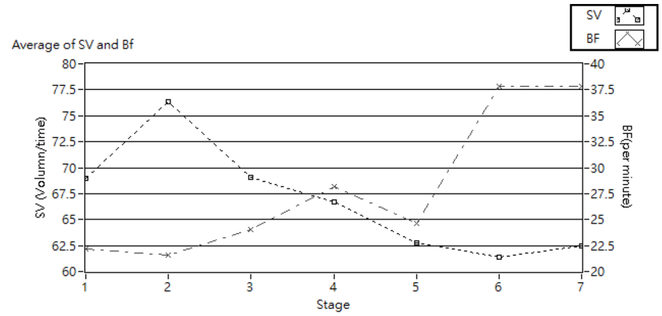

Figure 6. SV and BF change in the experiment

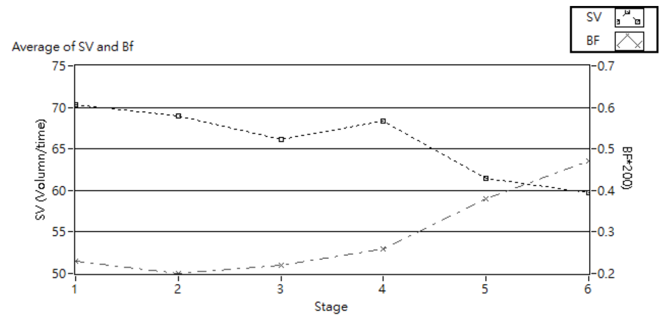

Figure 7. SV and BF change in woman

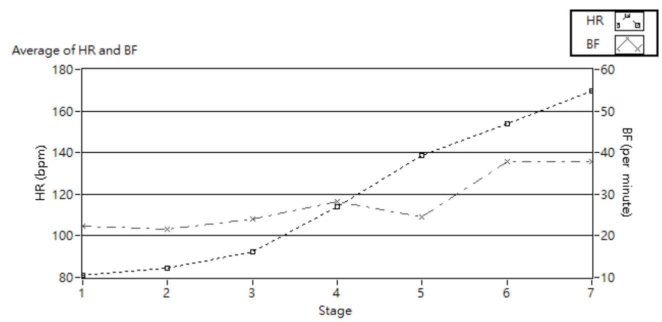

Figure 8. HR and BF change in man

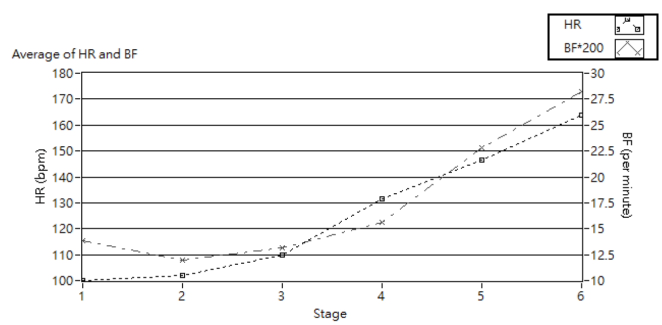

Figure 9. HR and BF change in woman

IV. Discussion

In this experiment, we observe the change in BF, SV, CO, and HR during incremental exercise. SV decreases during exercise. CO, HR, and BF had an increasing trend. The reduction of SV was associated with HR in this study. BF affects hemondynamics [10]. HR reacted to temperature and breathing. In our experiment, we excluded the temperature situation. We show that BF and HR are influenced during exercising. SV is associated with BF and HR.

In this study, we had some limitations in this experiment. Ventilation is also an important parameter to figure the mechanism in blood flow [12]. Chantler et al. use the elastance of the vessel and derive the index of SV to figure out the mechanism of the cardiovascular system during exercise [13]. There is still a big issue in stroke volume and breath during exercise. In future work, we will increase the number of subjects and provide more data to enhance the result. Moreover, we will use body mass index to separate and analyze different phases during exercising to explore the change.

V. Conclusion

In this study, we present a result of the breathing frequency and stroke volume situation during exercising. The result is an opposite change between breathing frequency and SV. HR interacts with breathing and indirectly influences stroke volume. In health care, we use the non-invasive way to measure BF and SV. It can help people to exercising at home. It can monitor the response during exercise. We show that HR and CO are increasing during exercising.

Acknowledgment

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TABLE II THE BREATHING FREQUENCY AND STROKE VOLUME DURING EXERCISING

Sex	Male		Female	
Parameter	Stroke volume (ml)	Breathing frequency (Hz)	Stroke volume (ml)	Breathing frequency(Hz)
Stage 1	69.00 ± 80.90	0.37 ± 0.23	70.31 ± 100.13	0.23 ± 0.16
Stage 2	76.35 ± 84.25	0.36 ± 0.09	68.89 ± 102.11	0.20 ± 0.12
Stage 3	69.07 ± 95.52	0.4 ± 0.21	66.13 ± 109.89	0.22 ± 0.11
Stage 4	66.71 ± 113.91	0.47 ± 0.28	68.51 ± 137.28	0.26 ± 0.10
Stage 5	62.79 ± 141.47	0.41 ± 0.25	61.38 ± 146.46	0.38 ± 0.12
Stage 6	61.34 ± 154.12	0.63 ± 0.39	59.71 ± 166.99	0.47 ± 0.18
Stage 7	62.50 ± 169.86	0.63 ± 0.29		

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