Modelling and Regulating of Cardio-Respiratory Response for the Enhancement of Interval Training

By

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Certificate of Original Authorship

I, Azzam Haddad, certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Date:

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ABSTRACT

Nowadays, interval training method becomes a well known exercise protocol which helps strengthen and improve one's cardiovascular fitness. It was first described by Reindell and Roskamm and was popularized in the 1950s by the Olympic champion, Emil Zatopek. Swedish physiologist Per Oløf Astrand's study in 1960 was the first scientific study on interval training. Since then, it has been the basis for athletic training programs for many years.

This thesis aims to develop an effective training protocol to improve cardiovascular fitness based on modeling and analysis of Heart Rate (HR) and Oxygen Consumption Rate (VO_2) dynamics. VO_2 and HR are key indicators of functional health status. Thus, investigating VO_2 and HR is important when building an effective training protocol because observing these two factors can help predict the amount of energy spent during training protocols which mainly used to determine goals such as fat burning or cardiovascular system improvement.

The first part of this thesis has considered conducting a certain number of experiments to investigate the dynamic characteristics of cardio-respiratory responses to the onset and offset exercises. The key device for this study is a portable gas analyzer ($K4b^2$,

Cosmed). This versatile portable device can measure HR and oxygen consumption both in field and lab environments.

Two different training protocols have been established for two different age groups. Each protocol has been tested separately. Observing the original data for each subject has clearly helped us to identify some important facts about HR and VO_2 profiles. It has been concluded that for each individual subject, steady state gain of offset is smaller than steady state gain of onset for both HR and VO_2. Based on the modelling results, it can be seen that the time constant of offset is larger than the time constant of onset for both HR and VO_2 in each group.

The second part of the thesis was all about building sensible interval training protocol based on the experimental results. Determining an actual HR_{max} is the key to constructing a well-designed training program. Our training protocol has targeted the aerobic zone which aims to develop the exercisers cardiovascular system. The third part in this thesis is to use the identified time constants and the steady state gains of VO_2 and HR for both the onset and offset of exercises to build a model to simulate the VO_2 and HR responses to the proposed interval training protocol. A switching RC circuit has been constructed to simulate the proposed interval training protocol.

The proposed interval training protocol is based on the established average model. However, for an individual exerciser the proposed protocol might need to be adjusted in order to achieve the desired exercise effects. A hybrid system model has been presented to describe the adaptation process and a multi-loop PI control has been developed for the tuning of interval training protocol. This thesis showed under modest assumptions that the special hybrid system can be simplified as a simple discrete time system. Based on that, we show how we can design a discrete time multi-loop PI controller to adjust the duty cycle and the period of the proposed square wave type exercise protocol.

We believe that the self-adaptation feature in the controller gives the exerciser the opportunity to reach his desired setpoints after a number of iterations. It should be emphasized that the proposed multi-loop PI control algorithm only performs one time between two training experiments. Therefore, it is very easy to be implemented in low cost portable devices which have limited computation power, and that is the final phase of this thesis. The control technique has been implemented and tested on eZ430 Texas Instrument programmable watch. Although further investigation is required and more subjects need to be recruited for the validation of this study, we believe that it will be useful in the modeling and regulation of interval training exercise in free living conditions.

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