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# Application of System Dynamics to Cardiovascular System Biofeedback Regulation of BP for Hypertensives

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## Abstract

The modern researches on physiology verify that there are close relationships between central nervous system (CNS) and autonomic nervous system (ANS) and some autonomic functions can be regulated by CNS to some extent. In this paper, the mechanisms of cardiovascular system, especially of BP regulation, under CNS control are researched. A blood circulatory system dynamic model is established and applied practically to treatment of hypertensives trained with biofeedbak technique, in which pulse transit time (PTT) is employed as an indirect index of BP change. The result shows that the cuartive effect of this method is efficient for BP control.

## Introduction

Cardiovascular diseases, especially hypertension, are very common in modern sociaty. There are evidences that essential hypertension is related to various behavioral, social, and environmental conditions. Many approaches to BP reduction have been developed. The behavioral approaches, such as biofeedback technique and meditation-relaxation, are some of them, with which, several disadvantages of medication treatment are prevented. Meaningful BP reductions were obtained in various literature sources [1,2], in which subjects were trained with biofeedback technique. But the measurement of BP is still an obstacle for BP Biofeedback program, in which it is also lack of research on theory. This paper attempts to make some contributions in these aspects.

With System Dynamics, we have researched the physiological mechanisms of cardiovascular system and presented its dynamic molel under CNS control. As an application, the model was used to instruct the biofeedback training of BP regulation for hypertensives, in which the BP was measured from PTT indirectly. The results from clinical practices shew this method is effecient for treatment of hypertension.

## Dynamics of Cardiovascular System and BP Control under CNS

It is able to analyze and model conveniently the circulatory system by means of System Dynamics. In this paper, the blood volume is refered to basic level variable, and based on the process of nervous adjusting of BP, the dynamic model of cardiovascular system is researched for cardiac rhythm and muscle adjusting on non-invasive measure and biofeedback control.

The circulatory system includes both pulmonary and systemic circulations. With the automatically rhythmical systole of sino-atrial node, cardiac impulses are transmitted to ventricular muscle through nerve fibers. In terms of Frank-Starling rule, the blood flowing in heart is completely injected into arteries. Under the action of pressure, blood flows from ventricles to arterioles, capillariesveins, finally, to vein in sequence. From fig.1, it can be found that there are two main factors which affect the arterial pressure: 1) cardiac otuput Q, 2) pripheral resistance R. The cadiac output is related to stroke volume (SV) and cardica rhythm (HF),

$$Q=SV*HF$$

According to the Frank-Staring rule, SV is equal to the venous return, which may also be adjusted by humoral system. The pripheral resistence

$$R=8\eta l/\pi r^{4}$$

where $\eta$ represents the blood viscosity, and $l$ and $r$ denote the length and the internal radius of the vessel, respectively.

During the process of nervous adjusting of BP, autonomic nervous control centers in lower level brain can inhibit vasomotor centers if they receive the signal of BP increasing, sametimes, excite vagal centers, as a result, the radius of vessel is expanded, the cardiac rhythm and contraction is weakened. Then the BP is decreased. In general, this kind of feedback control of BP is completed by pressurereceptors in aorta. But since the pressurereceptors may be adaptive to hypertension, and if it remains one or two days for increased BP they will loss their adjusting function. It makes that they are usefulless in treatment for hypertensives[3]. In terms of the principle of biofeedback technology, if BP is immediately reflected to CNS, the cardiovascular control centers will be stimulated to reduce BP by the regulating mechanisms existing between CNS and ANS. In fact, the practices in biofeedback technique and researches on nervous mechanisms have shown that there are close relationships between CNS and ANS. Many autonomic functions can be regulated by CNS with instruments outside body. With a BP receptor and feedback instruments, a new BP control system -- biofeedback control system is constructed, in which BP information is detected continuously and accurately by BP receptor and is sent efficiently to CNS by ways such as audition and vision etc., and then signals are in turn transmitted to ANS. Hence the vagal centers are excited and the stroke volume and peripheral resistance are changed, see fig.2. The feedback instruments outside body take an important role in BP regulation instead of pressurereceptors inside body. Through stimulating of gratified nervous centers and training gradually the subjucts may 'remenber' or 'enforce' the regulating process between CNS and ANS . By this way, the hypertensives can regulate the BP by themselves after a period of training so as to reach the goal of long-time treatment for hypertension. This system is self-learning and is described in the system dynamics model.

## PTT and Cardivascular Performence

It is very important to get information about activity of the autonomic function in biofeedback control system. General sphygmemanoment in which Korotkoff (K) sound is used to determine BP level, cannot be employed in biofeedback control program because of discrete and inaccurate. With an automated constant cuff-pressure system developed by D. Shapiro et al. [4][5], systolic blood pressure (SBP) or diastolic blood pressure (DBP) level can be measured beat-by-beat. But this has several disadvantages for psychophysiological experiments like biofeedback program etc.. Firstly, it has subjects fell uncomfortable, and secondly, the inflated cuff may cause the artery to be clogged or partly clogged. Arterial pulse transit time (PTT) has been used as a measure of cardiovascular performences in past decate [6]~[8], mainly as an index of BP change. In reference [9], Zhu Mingjie presented a new instrument to detect PTT with arterial pulse wave (PW) and electro-cardiogram (ECG) and established a model to describe the relationship between PTT and BP. The regression equation is:

$$\Delta MBP=-1.313*\Delta PTT$$

where MBP represents the change of mean BP (mmHg), and ΔPTT stands for the change of PTT (ms).

By this method, the change of BP can be detected continuously and noninvasively, which is desirable for biofeedback BP control experiments.

## Application to Biofeedback BP Control

a. Subjects and method

22 essential hypertensives were randomly assigned to three groups A,B, and C. They were asked to complete training session once daily 6 days a week for three weeks. A training session took approximately 30 minutes. Thus 18 sessions were completed for each subject over the training program.

Subjects in feedback session were given feedback information about their BP change measured with PTT indirectly, in pseudo-feedback session, the subjects were given random sigals which were irrelevent with their BP. In relaxation session, subjects were asked to sit quietly, relax their muscles, without feedback information. Subjects in group A were trained with feedback session in whole program, these in group B were trained with feedback and relaxation session alternately and in group C they were trained with pseudo-feedback session.

In biofeedback session, PTT was used as a measure of BP change. The PTT was got from the arterial pulse wave(PW) and electrocardiogram(ECG), where the PW was detected with a photo-electronic transducer, and ECG was got from standard lead II.

b. Results

1). There are significant BP reductions in both group A and group B over three weeks, average magnitudes are 27.8/22.6 mmHg (see fig.3) and 24.5/16.9 mmHg, respectively. But significant differences between them cannot be found.

2). There is no significant change in average BP of Group C over the Program.

3). There is significant differences between biofeedback and relaxation in within-session average SBP reduction (average reductions are 6.9 mmHg and 4.7 mmHg respectively).

4). There are no significant across-session reductions in average magnitutes of BP for either relaxation or pseudo-feedback session.

5). Mean reduction of SBP for biofeedback session is significant, magnitude is 6.9 mmHg.

## Discussion

Significant BP reductions of subjects trained with biofeedback technique successively is obtained, average magnitude is 27.8/22.6 mmHg (the last three to the first three sessions). This is superior to other reported results [1][2] and supports the suggestion that voluntary regulation of some autonomic functionl may be helpful for clinical treatment of the deseases caused by stress, mainly hypertension. In addition, It is also found that there are major differences between hypertensives and normal persons on the distributions of the PTT parameter and its components -- the cardiac pre-ejection period (PEP) and the pulse transit interval (PTI). The PEP and PTT also provide some information about cardiovascular performence. By means of model and method of System Dynamics, computer technology, artificial intelligence and modern electronic techniques, a computer-aidded diagnosis and treatment system can be constructed in which experiences of experts and various parameters reflecting cardiovascular activity such as PTT, PEP, PTI and etc. are useful.

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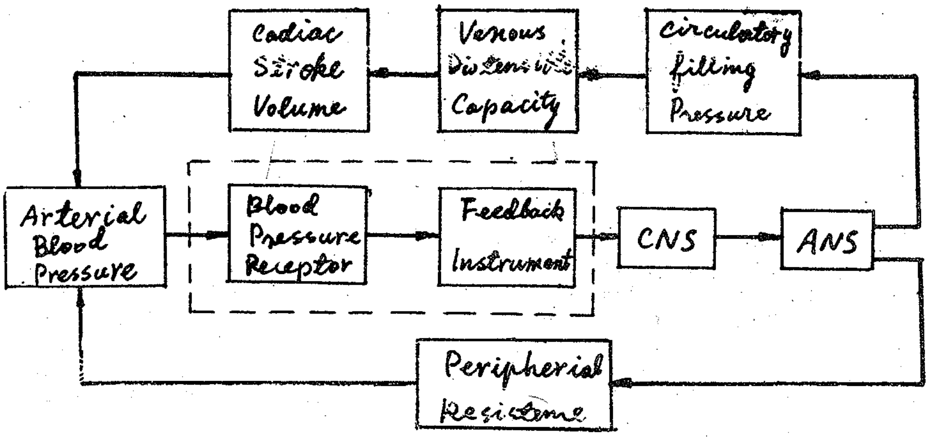


Fig.2: Diagram of biofeedback control of BP

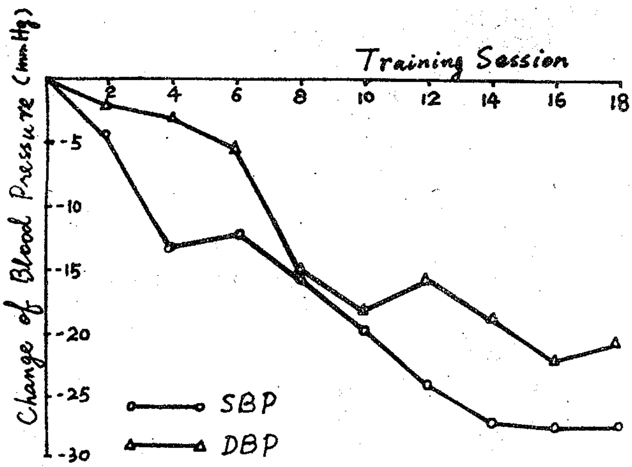


Fig.3: Changes of BP during the program

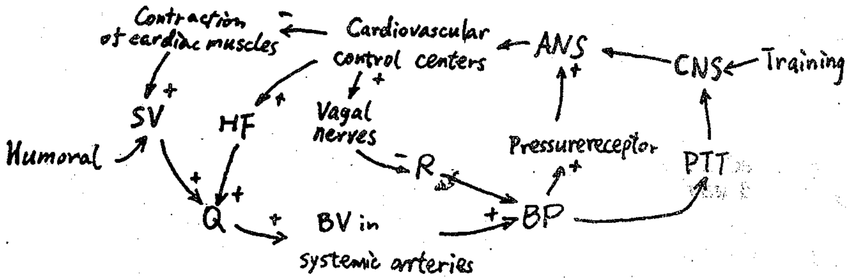


Fig. : Cause-effect diagram