Experiment HP-5: Heart Rate, Blood Pressure, and Vagal Tone

What Determines Heart Rate?

Heart rate is the number of beats per minute of the heart (BPM) and it is determined by factors intrinsic to the heart, as well as regulatory pathways from the brain and hormonal signals from the adrenal gland. Once again, when the brain is involved, psychological states may show themselves in the peripheral response.

Factors intrinsic to the heart include pacemaker cells (from the SA node) which discharge electrical signals to the heart muscle in order to initiate the heart beat. Sometimes these signals become disordered and the heart may beat irregularly. You've probably all seen media examples of dramatic efforts to restore a normal heart beat in the emergency room with a defibrillator. The defibrillator can sometimes stabilize a chaotic or irregular heart rhythm or it can sometimes restore a heart beat when it has ceased.

The obvious purpose of the heart beat is to move blood around the body. The rate of the heart beat is one factor which influences cardiac output and the volume and speed of delivery of the blood to body cells. Clearly, there are times when the blood needs to reach those cells more or less quickly. Exercise, responding to stressors, and even just standing up may create greater cellular needs for oxygen and blood nutrients (mainly glucose). Relaxation, sleeping and other vegetative states generally create a reduced cellular need. Sensors in the brain stem and hypothalamus provide feedback regulation of the heart rate to meet the demands of body cells. Responding to stressors involves the activation of higher limbic system structures such as the amygdala and hypothalamus, which then send signals via the autonomic nervous system to increase (or decrease) the heart rate. Neurotransmitter signals from the sympathetic branch (norepinephrine) increase the heart rate (by binding to beta1-adrenergic receptors), while neurotransmitter signals from the parasympathetic branch (acetylcholine) decrease the heart rate (by binding to muscarinic cholinergic receptors).

There are individual differences in the resting heart rate which are related to genetics, gender (females generally have faster heart rates than males), and to physical condition (state of health as well as fitness). Also, there are individual differences in the size (and sometimes the direction) of the adaptive changes which take place in response to environmental events. Some of these differences are related to personality, psychological state, and perhaps fitness as well.

What Determines Blood Pressure?

When the heart beats it pumps blood through the circulatory system (arteries, arterioles, capillaries, venules, veins) to deliver blood to cells. The elements of the circulatory system are composed of smooth muscle cells and membranes to contain the blood. In its progress around the body, the nutritive elements are transported out of the blood to cells and the waste products of cells are transported into the blood for elimination from the body. The blood vessels exert a certain pressure on the blood, which depends in part on their elasticity and in part on neural and hormonal signals to the vessels. The elasticity of the blood vessels is limited by the build up of plaque (lipid/protein/immune cell deposits in the walls of the blood vessels) and elasticity generally decreases with the presence of certain lifestyle factors (diet, alcohol, smoking, lack of exercise) and with age.

Blood pressure is measured non-invasively with a sphygmomanometer. A pressure cuff is placed around the upper arm and inflated while the heart sounds (Korotkoff-sounds or K-sounds) are monitored. The cuff is inflated to block the flow of blood to the arm and then deflated slowly to determine two values. The first value is the amount of pressure in the cuff when the heart sounds (actually the turbulence of the blood as it rushes through the now open artery) are first heard in the arm after being blocked. This is termed the *systolic blood pressure* (SBP). The SBP is the pressure the arteries exert on the blood flow when the heart ventricles are contracting. The second value is the amount of pressure in the cuff when the heart sounds in the arm are gone and it is termed *diastolic blood pressure* (DBP). The DBP is the pressure the arteries exert on the flow of blood when the ventricles are relaxing and being filled by the atrial contractions. The blood pressure is reported in pressure units of mmHg and a typically normal blood pressure for a young person is about 120/80 (SBP/DBP).

Blood pressure is just another one of several factors which determine the delivery of blood to the cells. As in heart rate, the blood pressure is determined in part by factors intrinsic to the blood vessels themselves (elasticity) and by regulatory neural signals from the brain and hormones from the adrenal glands and kidneys. Obviously, if a substance needs to be moved quickly to the place where it is needed, it is important to be able to increase the rate of beating of the pump and the pressure on the contents of the delivery system. The neural and hormonal control of blood pressure is a complicated orchestration of constriction and dilation of vascular beds to achieve the adaptive delivery of blood to tissues in need.

Psychological States and Cardiovascular Responses

Cardiovascular responses have been studied most often in the context of arousal and emotional states. The stress response ("fight or flight") is a physiologically adaptive set of bodily changes in the presence of a life threat or a threat to one's self worth. In general, activity of the sympathetic nervous system is enhanced, bringing about elevations in heart rate and blood pressure necessary to deal with the perceived threat. These responses are adaptive in the short term and generally improve human performances which require speed, strength, and endurance. Human performance which requires fine motor skills or complex cognitive processes is generally affected in a curvilinear fashion; performance is enhanced with moderate or optimal levels of the stress response, but hindered with high levels of the stress response (as anyone who plays the piano knows).

Studies have shown that anxiety, frustration, anger, fear, anticipation of pain and other negative emotional states can bring about elevations in heart rate and/or blood pressure. Positive emotional states of excitement, joy, and interest can also bring about elevated cardiovascular responses. There are, however, individual differences in the nature and the extent of cardiovascular responses in emotional states. Some of these differences stem from the nature of the individual personality (for example cynicism and hostility) and some stem from the nature of the environmental demands. Complicating the picture is the fact that heart rate and blood pressure may disassociate in response to environmental events. Research has supported the idea that tasks which require environmental intake or monitoring, cause heart rate lowering (blood pressure may rise or remain unchanged), while tasks which require environmental rejection (events which are aversive or bring about escape motivations) result in heart rate and blood pressure elevations. Similarly, it has been shown that tasks which tend to produce anxiety and self-focus (for example giving a speech if you have presentation anxiety) tend to elevate heart rate and blood pressure, while tasks which tend to produce anxiety and environmental-focus (for example listening to a lecture that you will be tested on later) tend to reduce heart rate while blood pressure may elevate or remain unchanged.

There are many complexities in the cardiovascular research literature and also many controversies. One interesting controversy deals with the degree to which physical fitness can perhaps mute the stress response to a psychosocial stressor. Physical conditioning of an aerobic nature has been shown in some experiments to reduce the stress response (or enhance recovery to pre-stress values) to a cognitive stressor task such as mental arithmetic. In other experiments, the baseline values are lower in persons who engage in aerobic activities, but the change over baseline is shown to be about the same as in persons who are not physically active. Sports psychologists have conducted many experiments on this aspect of psychophysiology.

What is Vagal Tone?

The parasympathetic nervous system influences the tonic or resting heart beat by means of signals from the tenth cranial nerve, the Vagus. Even at rest, a person's heart rate will fluctuate with his or her breathing cycle. Inspiration triggers an increase in heart rate, but this increase occurs after maximum inhalation. The latency between maximum inhalation and maximum heart rate is the time required for receptor (stretch, baro-, pH, O_2, CO_2) signals in the organ systems to be integrated, motor signals to be generated in control centers, and impulses to be delivered to effector organs (cardiac, skeletal, and smooth muscles). Conversely, expiration triggers a decrease in heart rate. The recording, shown in Figure HP-5-B1, is an example of this phenomenon.

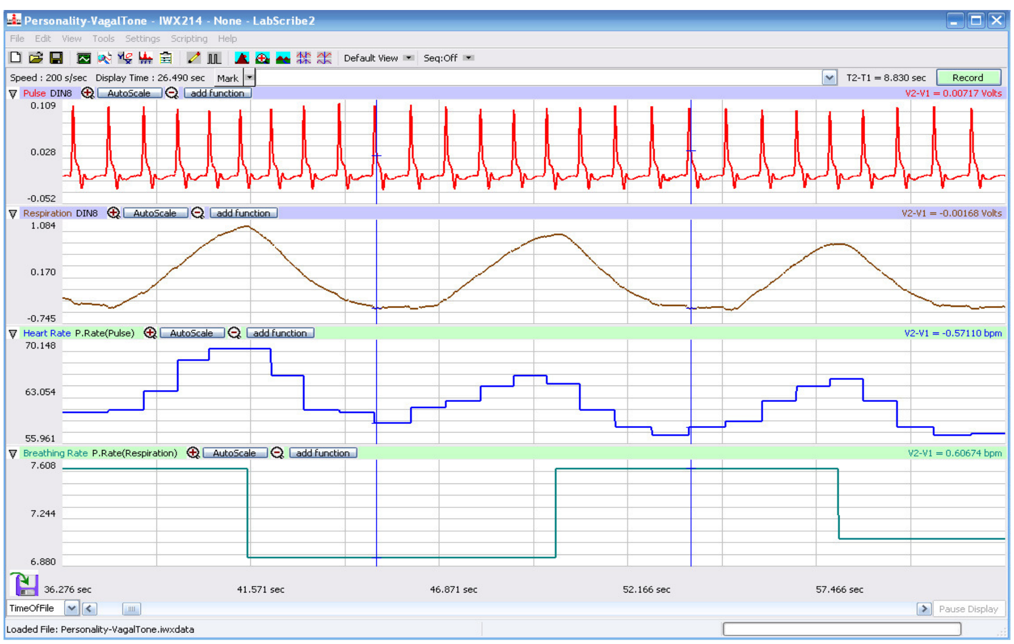

Figure HP-5-B1: This is an example of respiratory sinus arrhythmia. The outputs of the pulse plethysmograph and the respiration monitor are recorded on the two uppermost channels. The heart and breathing rates are recorded on the next two channels. The maximum heart rate occurs after the completion of inhalation (peak of respiration cycle).

Notice that the change in the heart rate is in phase with the respiratory cycle. The change in the heart rate that results from breathing is known as respiratory sinus arrhythmia (RSA). The extent of the RSA is a rough measure of Vagal control over the resting heart beat, referred to as Vagal tone. The size of the RSA (degree of variability of the heart rate for each respiratory cycle) is what is determined by the Vagus nerve. When the heart rate varies considerably for each respiratory cycle, then we say there is good or high Vagal tone. When the heart rate is relatively steady with low variability for the respiratory cycle, we say there is poor or low Vagal tone. In general Vagal control over the heart rate lessens during stressful experiences when sympathetic activity is heightened, thus allowing the heart rate to rise to meet the challenge.

Personality and Vagal Tone

Vagal tone has been related to temperament (the innate "building blocks" of personality) and stress vulnerability in children. Children who show behavioral inhibition in novel situations (somewhat comparable to shyness) have low Vagal tone as evidenced by higher and less variable resting heart rates. Preschoolers who fail to show emotional expression also have low Vagal tone and may be vulnerable to depression and anxiety in later years. There is also evidence that adults who are extremely shy or behaviorally inhibited have higher and less variable resting heart rates. Also adults with high Vagal tone may have lower blood pressure responses to stress, making them less vulnerable to hypertension and coronary heart disease. Interestingly, adults with high Vagal tone are more susceptible to hypnosis. The exact relationship between the autonomic nervous system's regulation of physiological responses and personality is unknown, but many hypothesize that the innate sensitivity and reactivity of the nervous system may be the fundamental mechanism for biasing personality development and expression. You might want to read more about this interesting topic; a few references are provided at the end of this chapter.

In this experiment, you will collect and analyze heart rate and blood pressure data during:

- a baseline period;
- a mild cognitive stressor (spelling words backwards aloud);
- a vigilance reaction time task.

Warning: *As explained above, this procedure involves stopping blood flow to the arm, which is potentially dangerous. Please take the following precautions.*

Precautions

1. Know what you are doing ahead of time.
2. Do not leave the cuff inflated for any prolonged period of time (>20 seconds).
3. The subject should flex and extend their fingers between experiments to maintain blood flow.
4. This experiment should be performed by healthy individuals who do not have a personal or family history of cardiovascular or respiratory problems. It is preferable to use more than one subject during the course of the lab session.