Advanced BME Laboratory (AM5019)
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EXPERIMENT 1: Valsalva maneuver

AIM:
To study and understand the control mechanism of the heart.

OBJECTIVE:
i. Record the PPG to obtain the heart rate during normal breathing for three intervals:
   a. inhalation; b. holding of breath; c. exhalation
ii. Record the PPG data to obtain the heart rate while applying a constant force to a hand gripper (isometric compression) for three intervals:
   a. inhalation; b. holding of breath; c. exhalation
iii. Observe the heart rate variability in the above cases and perform time-domain analysis.

THEORY:

Valsalva maneuver

The Valsalva maneuver is a breathing method that can slow down the heart rate and restore a normal heart rate when the heart is beating too fast.
The Valsalva maneuver can be performed by following the steps in order for 10-15 seconds:
1. Pinch the nose closed.
2. Close the mouth.
3. Try to exhale, as if inflating a balloon.
4. Bear down, as if having a bowel movement.

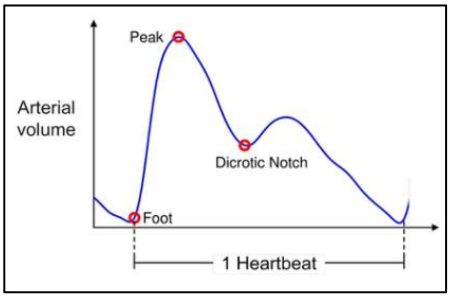
The Valsalva maneuver can be divided into four phases:
Phase one: Blowing air against closed airways causes the pressure in the chest to increase. Blood is forced out of the heart to the body and caused a transient rise in blood pressure.
Phase two: It causes a steady drop in blood pressure as a limited amount of blood in the veins returns to the heart. The lower amount of blood returning to the heart results in less blood pumped from the heart and a fall in blood pressure. The ANS senses this pressure drop and activates the baroreceptors in the carotid sinus and aortic arch. The vagal withdrawal followed by increased sympathetic discharge ensues, leading to marked tachycardia, increased cardiac output, and vasoconstriction which leads to the recovery of blood pressure to the normal values in healthy individuals.

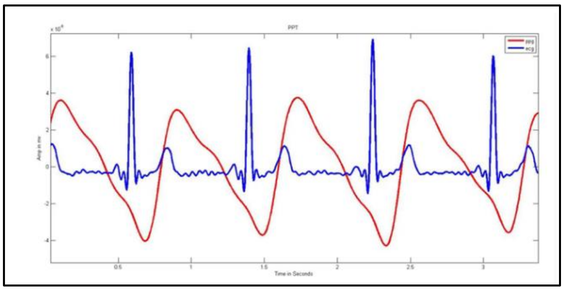
Phase three: At the end of the maneuver, relaxing causes a sudden dip in the blood pressure. The release of positive pressure leads to expansion of the pulmonary vascular bed and reduces left ventricular cross-sectional area resulting in a transient fall in blood pressure.
Phase four: There is an overshoot of the blood pressure above the baseline, due to resumption of normal venous return to the heart stimulated by the sympathetic nervous system during Phase II. The overshoot of blood pressure leads to stimulation of baroreflex leading to bradycardia and return of blood pressure to the baseline.

The two important purposes of the Valsalva maneuver are:

1. Restoring heart rhythm: The shifts in blood pressure and heart rate during the four phases of the maneuver can often restore a normal heart rhythm when the heart is experiencing tachycardia.
2. Diagnosing an ANS disorder: The pattern of heart rate and blood pressure changes during the Valsalva maneuver can help identify problems with sympathetic and parasympathetic functions.

Photoplethysmography (PPG)





https://training.ti.com/how-measure-ecg-ecg-vs-ppg

Photoplethysmography (PPG) is a simple, non-invasive optical technique used to detect volumetric changes in the microvascular bed of tissue. When light travels through biological tissues it is absorbed by bones, skin pigments and blood. Since light is more strongly absorbed by blood than the surrounding tissues, the changes in blood volume flow can be detected by PPG sensors as changes in the transmitted or reflected intensity of light. The voltage signal from PPG is proportional to the quantity of blood flowing through the blood vessels. In addition, small changes in blood volume can be detected using this method, though it cannot be used to quantify the amount of blood. A PPG is often obtained by using a pulse oximeter.

Since, blood flow to the skin can be modulated by other physiological systems, the PPG can also be used to monitor breathing, hypovolemia, and other circulatory conditions. In addition, the shape of the PPG waveform varies between individuals, and with the location and placement of the pulse oximeter. The PPG signal comprises pulsatile (AC) and superimposed (DC) components. The AC component is provided by the cardiac synchronous variations in blood volume that arise from heartbeats. The DC component is shaped by respiration, sympathetic nervous system activity, and thermoregulation. The AC component depicts changes in blood volume, which are caused by cardiac activity and depend on the systolic and diastolic phases. The systolic phase (rise time) starts with a valley and ends with the pulse wave systolic peak. The pulse wave end is marked by another valley at the end of the diastolic phase. Features such as rise time, amplitude, and shape can predict vascular changes in the bloodstream. Each cardiac cycle sends a pressure wave through the cardiovascular system. This pressure wave causes the blood vessels to expand and contract, which gives the PPG a characteristic waveform. Since the period of the PPG waveform repeats with each cardiac cycle, it can be used to calculate a patient's heart rate. In a healthy individual, the heart rate (heart beat) is in sync with the pulse rate (rate of blood pressure). Thus, peak-peak interval of the PPG signal can be used to measure Heart rate.

Heart rate variability (HRV):

A complex and constantly changing heart rate (HR) is an indicator of healthy regulatory systems that can effectively adapt to sudden environmental and psychological challenges. The physiological mechanism underlying HRV highlights the coupling between the brain and the body. HRV reflects regulation of autonomic balance, blood pressure (BP), gas exchange, gut, heart, and vascular tone, which refers to the diameter of the blood vessels that regulate BP. The SA node, that dictates the rhythm of heart contractions, is in turn controlled by the complex interactions between different regulatory systems and mechanical activities such as respiration. As the interdependent sources of HR operate on different time scales, HRV is itself unevenly distributed in different frequency bands, with high and low frequency changes corresponding to different neurophysiological mechanisms. Rapid changes of HR reflect the cardiac regulatory influences of the autonomic nervous system (ANS) along with its dynamic interaction with cardiovascular and respiratory activities. Slow HR changes reflect bodily fluctuations of lower frequency, such as circadian rhythms, sleep cycles, metabolism, and changes in body temperature and hormonal systems. Higher HRV is not always good since pathological conditions can produce HRV. When cardiac conduction abnormalities elevate HRV measurements, there is increased risk of mortality.

Time-domain analyses performed for given data:

SDRR (ms):

The standard deviation of the inter-beat intervals (IBIs) for all sinus beats (SDRR), including abnormal or false beats. The SDRR measures how these intervals vary over time and is more accurate when calculated over 24 h. A longer period is preferred since it is representative of slower processes and the cardiovascular system’s response to more diverse environmental stimuli. Abnormal beats may reflect cardiac dysfunction or noise that manifests as HRV

RMSSD (ms):

The root mean square of successive differences between adjacent RR intervals, measured in ms. The RMSSD reflects the beat-to-beat variance in HR and is the primary time-domain measure used to estimate the vagally mediated changes reflected in HRV

Range: HR Max – HR Min (beats/min):

The average difference between the highest and lowest HRs during each respiratory cycle (HR Max – HR Min) is especially sensitive to the effects of respiration rate, independent of vagus nerve traffic.

APPARATUS & SOFTWARE USED:

PPG sensor, Arduino, connecting wires, breadboard, MATLAB programming interface to visualize and process PPG signal.

PROCEDURE:

i. The subject was made to sit in a comfortable position. The ppg sensor was placed on the index finger of the left hand.

ii. The ppg signal was recorded for one normal breath:

   a. 0-3 seconds (slow inhalation), b. 3-15 seconds (holding of breath), c. 15-20 seconds (exhalation)

iii. Next, the subject was asked to compress the hand-gripper with the right hand by applying a constant force over the duration of one breath. The ppg signal was recorded for one breadth under hand-grip exercise-

   a. 0-3 seconds (slow inhalation), b. 3-10 seconds (Holding of breath), c. 10-15 seconds (Exhalation)

iv. The heart rate was observed in both the cases and HRV time-domain analysis was performed.

RESULTS & CALCULATIONS:

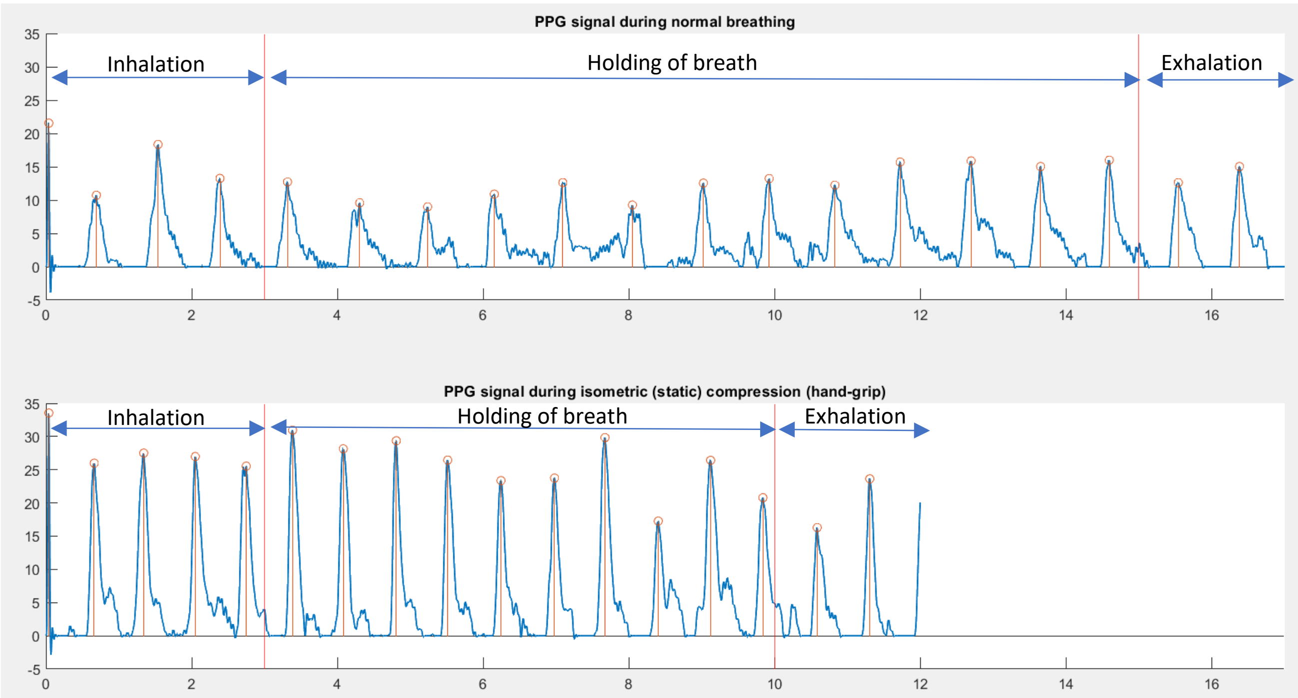


Fig1: PPG signal waveform

The voltage output of the PPG sensor is directly proportional to blood pressure. From Fig1, it can be observed that during the hand grip exercise (application of a constant static force), the blood pressure (systolic – diastolic BP) is much higher than in the case of normal breathing. This can be attributed since the subject is under constant external stress, requiring the heart to pump more blood during exercise. Isometric exercise is characterized by promoting a pressure overload on the cardiovascular system due to pulsatile contraction followed by a significant increase in muscle blood flow.

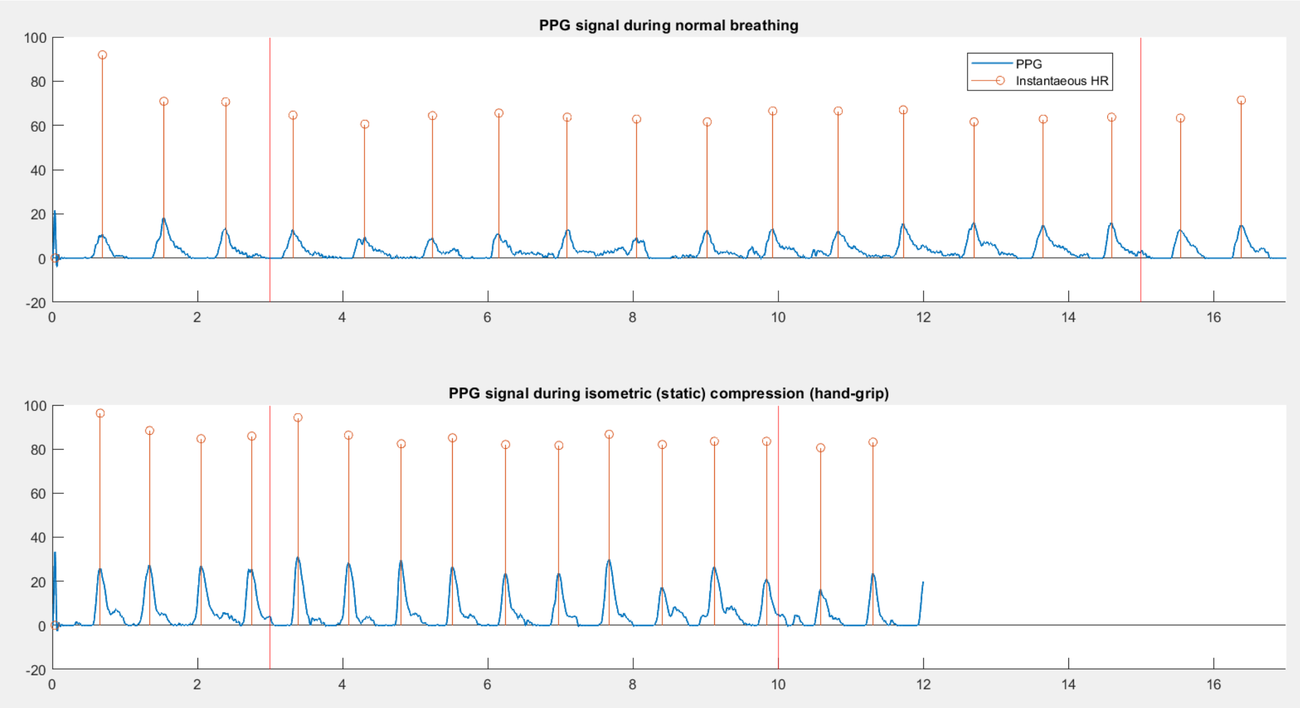


Fig2: PPG signal and instantaneous heart rate

From Fig2, the heart rate is significantly elevated while performing the hand-grip exercise vs normal breathing.
Mean heart rate during normal breathing = 70.1133 beats/min
Mean heart rate during hand-grip exercise = 85.4054 beats/min

Parameter	During normal breathing	During hand-grip exercise (applying a constant static force)
Mean heart rate (beats/min)	70.1133	85.4054
SD Heart rate (beats/min)	11.9637	4.4004
Mean (RR) (seconds)	0.8747	0.7042
SDRR (ms)	117.2495	34.0598
RMSSD (ms)	882.1194	704.9468
Range: HR Max – HR Min(beats/min)	41.0542	15.6928

From the calculated time domain parameters, it is observed that the standard deviation of the RR interval (SDRR), RMSSD and range is higher during normal breathing vs during the hand-grip exercise.

Several studies have demonstrated that hand-grip exercise can modulate the ANS and as is proposed as an alternative to treating and preventing systemic hypertension, as studies have shown that this type of training reduces blood pressure. However, few studies have shown that hand-grip exercise has no effect on blood pressure.
A study (Banerjee 2017) observed differences in HRV frequency components calculated for diseased patients with glaucoma vs healthy patients while performing the hand-grip activity.
Another study (Andrade 2021) found that Hand grip exercise reduced resting heart rate and induced marked shifts in HRV towards parasympathetic predominance. They report that deep breathing along with Hand-grip exercise and circulatory occlusion improves cardiac autonomic modulation in healthy young adults.
To validate the results of Andrade 2021 PPG data is needed before and during recovery post hand-grip exercise.

CONCLUSIONS:

Even with small durations of PPG data (~15 sec), it is possible to observe the dynamic changes of the heart rate and blood pressure. The parameters observed are different at normal resting state and when subject to hand-grip exercise.

CRITICAL REMARKS:

i. To accurately make correlations and study HRV longer durations of recordings are needed.
ii. Data before and after hand-grip exercise from different subjects is needed to study the effect of hand grip exercise and validate its use in improving autonomic activity.

REFERENCES:

1. Andrade DC, Melipillan C, Toledo C, Rios-Gallardo A, Marcus NJ, Ortiz FC, Martinez G, Muñoz Venturelli P, Del Rio R. Heart rate and cardiac autonomic responses to concomitant deep breathing, hand grip exercise, and circulatory occlusion in healthy young adult men and women. Biol Res. 2021 Sep 26;54(1):32. doi: 10.1186/s40659-021-00355-1. PMID: 34565477; PMCID: PMC8474820.

2. Banerjee A, Khurana I, Effect of isometric handgrip test on heart rate variability in primary open angle glaucoma. Indian J Clin Anat Physiol 2017;4(1):4-7