Topic 5

Measuring Pulse Rate with Smart Devices

Learning Objectives

With the advancement of technology, monitoring one's own health has become easier. The use of wearable devices such as smart watches to monitor heart rate, physical activity and other health metrics has become increasingly prevalent. In this topic, we will explore the scientific principles and technology behind these convenient health monitoring devices through the following activities:

Activity I

Pulse rate measurement using pulse sensor

Activity II

Effects of exercise on pulse rate

Background knowledge: human circulatory system

Human circulatory system (Fig. 1), also known as cardiovascular system ("cardio-" or "cardiac" refers to heart, and "vascular-" refers to blood vessels) is a closed loop system which consists of three main components:

- ***Blood***
  with a red pigment called haemoglobin to carry oxygen;
- ***Blood vessels***
  which include arteries, veins and capillaries; and
- ***Heart***
  which acts as a pump, to drive blood throughout the body.
  (See Fig. 2 for its structure)

The main function of human circulatory system is to carry oxygen, nutrients and hormones to different parts of human body, while also removing carbon dioxide and metabolic waste from cells and organs.

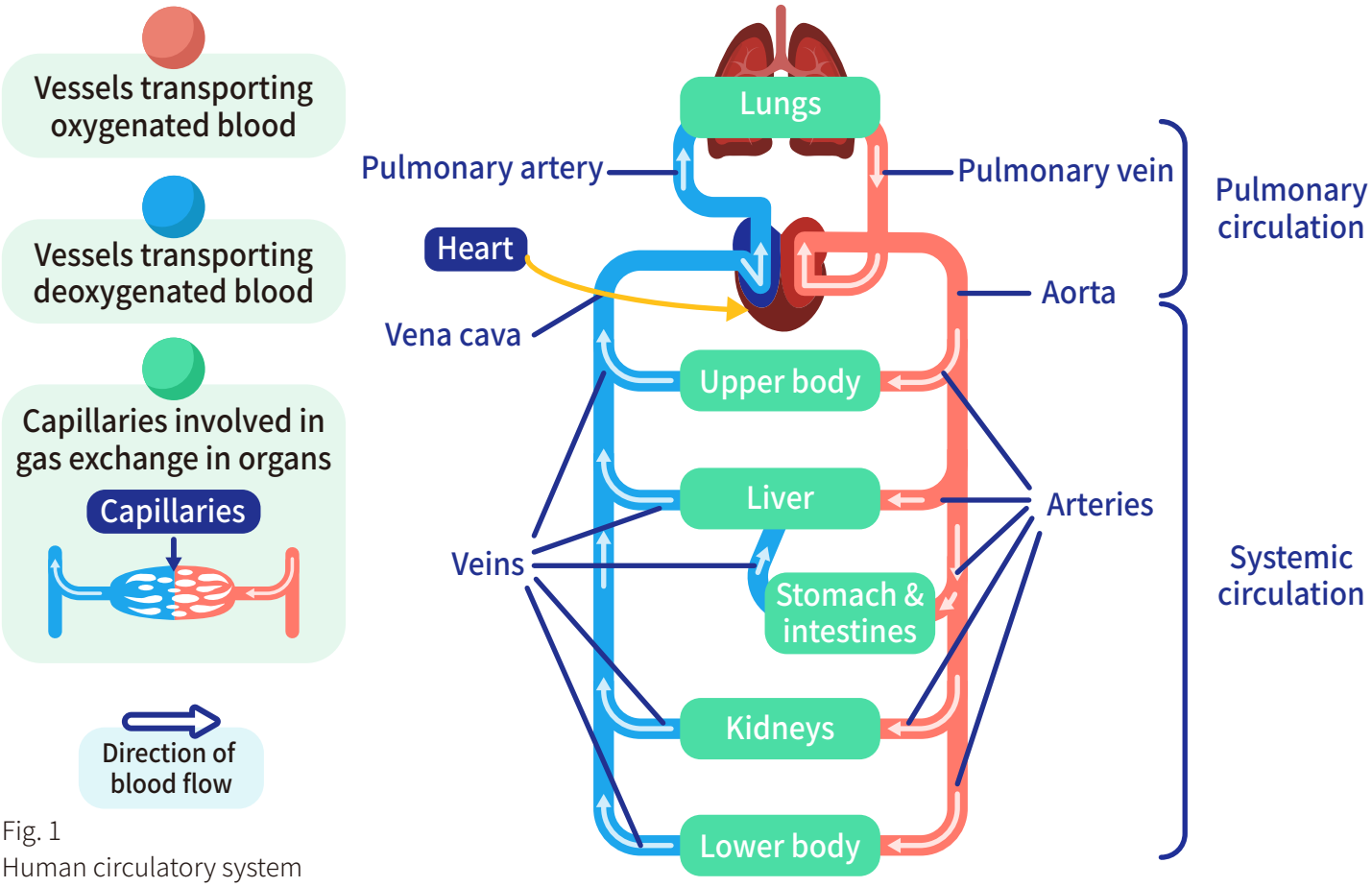


Fig. 1
Human circulatory system

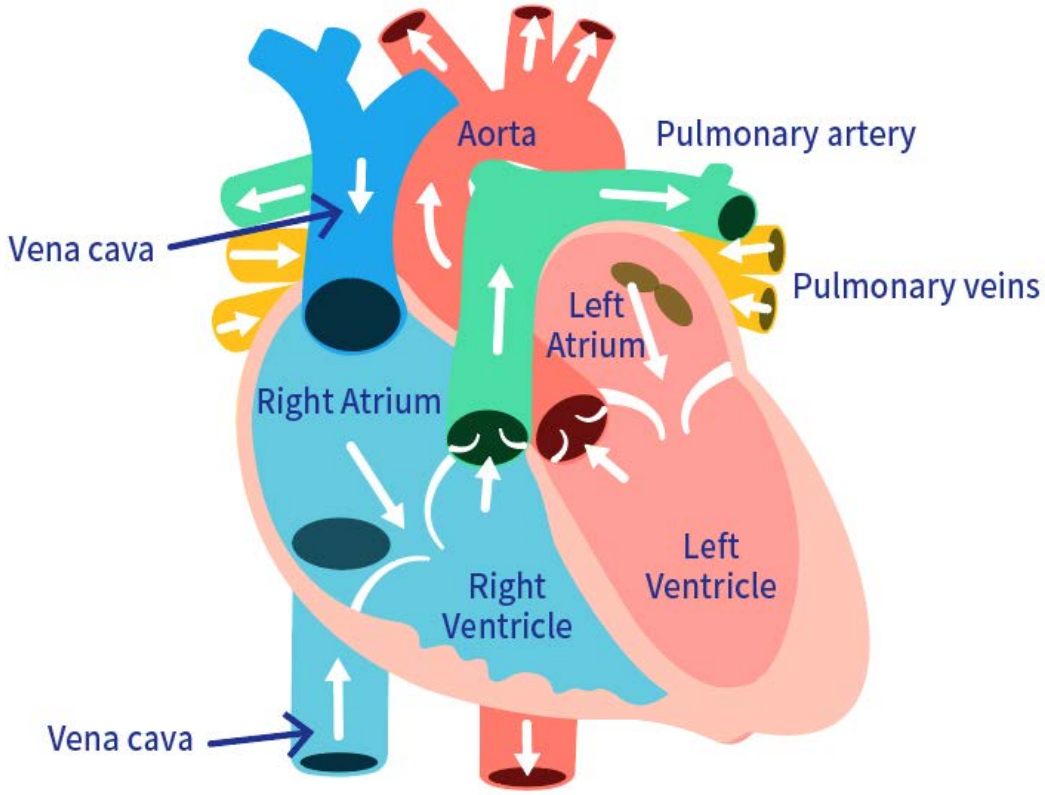


Fig. 2
Basic structure of heart

Background knowledge: cardiac cycle

There are two phases for the heart's pumping cycle (also known as cardiac cycle) (Fig. 3):

- ***Systole*** – the stage when the heart contracts and pumps the blood out of the heart chambers into the arteries, resulting in systolic blood pressure in the arteries.
- ***Diastole*** – the stage when the heart relaxes and fills the heart chambers with blood from the veins, resulting in diastolic blood pressure in the arteries.

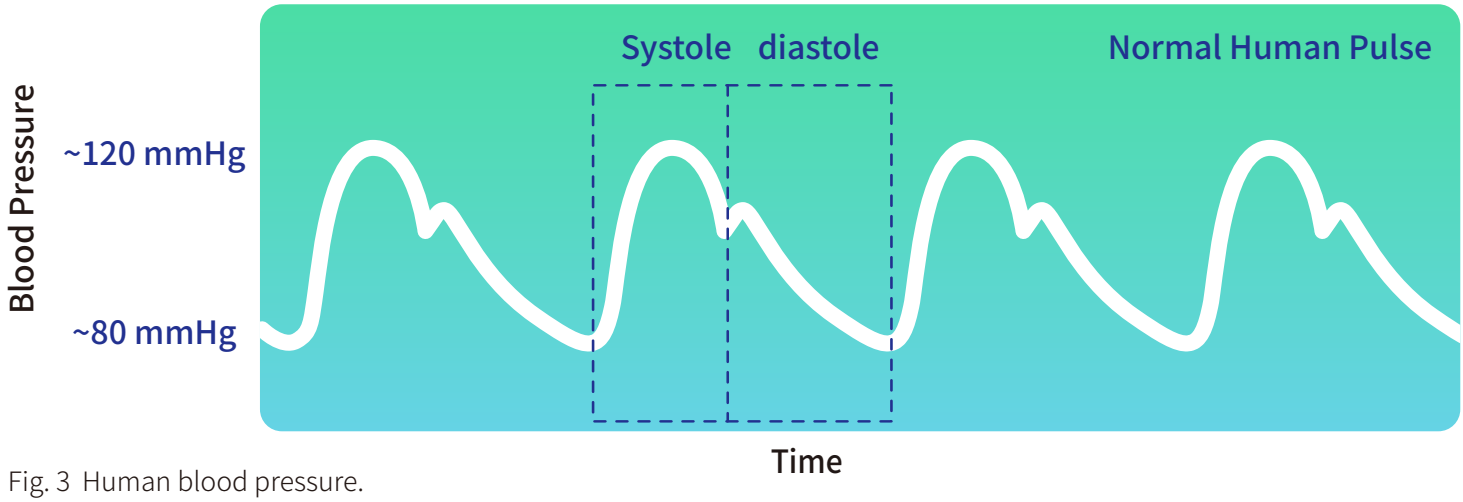


Fig. 3 Human blood pressure.

Heart rate and pulse rate

Strictly speaking, heart rate and pulse rate are different. However, pulse rate is essentially a reflection of heart rate.

Heart rate

- Heart rate is ***the number of times the heart beats per minute***, which is normally between 60 and 100 times per minute for adults at rest.

  It can be influenced by various factors such as physical activity, stress and medications.

Pulse rate

- A pulse is the rhythmic expansion and contraction of an artery resulting from the beating of the heart.
- Pulse rate is ***the number of times the heart beats per minute that can be felt through the increase in arterial pressure*** when blood is pumped into the body by the heart.
- It can be influenced by various factors such as blood pressure and the elasticity of the arteries.

Activity I
Pulse rate measurement using pulse sensor

Introduction

In this activity, we will measure and calculate our pulse rate using a DIY pulse sensor utilised by photoplethysmoraphy (PPG).

Working principle: Photoplethysmography (PPG)

Heart contractions produce an increased blood volume in arteries, whereas heart relaxations produce a decreased blood volume. PPG is an optical method for detecting blood volume through a light beam (emitted by a green, red, or infrared LED) either passing through or being reflected by the volume of blood.

The amount of transmitted or reflected light can be measured by a light detector (e.g. a photodiode) in a PPG sensor which turns the variation of blood volume into pulse signals. PPG sensors can be the transmission or reflective type (Fig. 4). These sensors are usually placed on body parts where blood vessels are close to the surface of the skin, such as earlobe, wrist, ankle and fingertip (Fig. 5). This technology is widely used in wearable devices such as smartwatches to monitor the pulse rate.

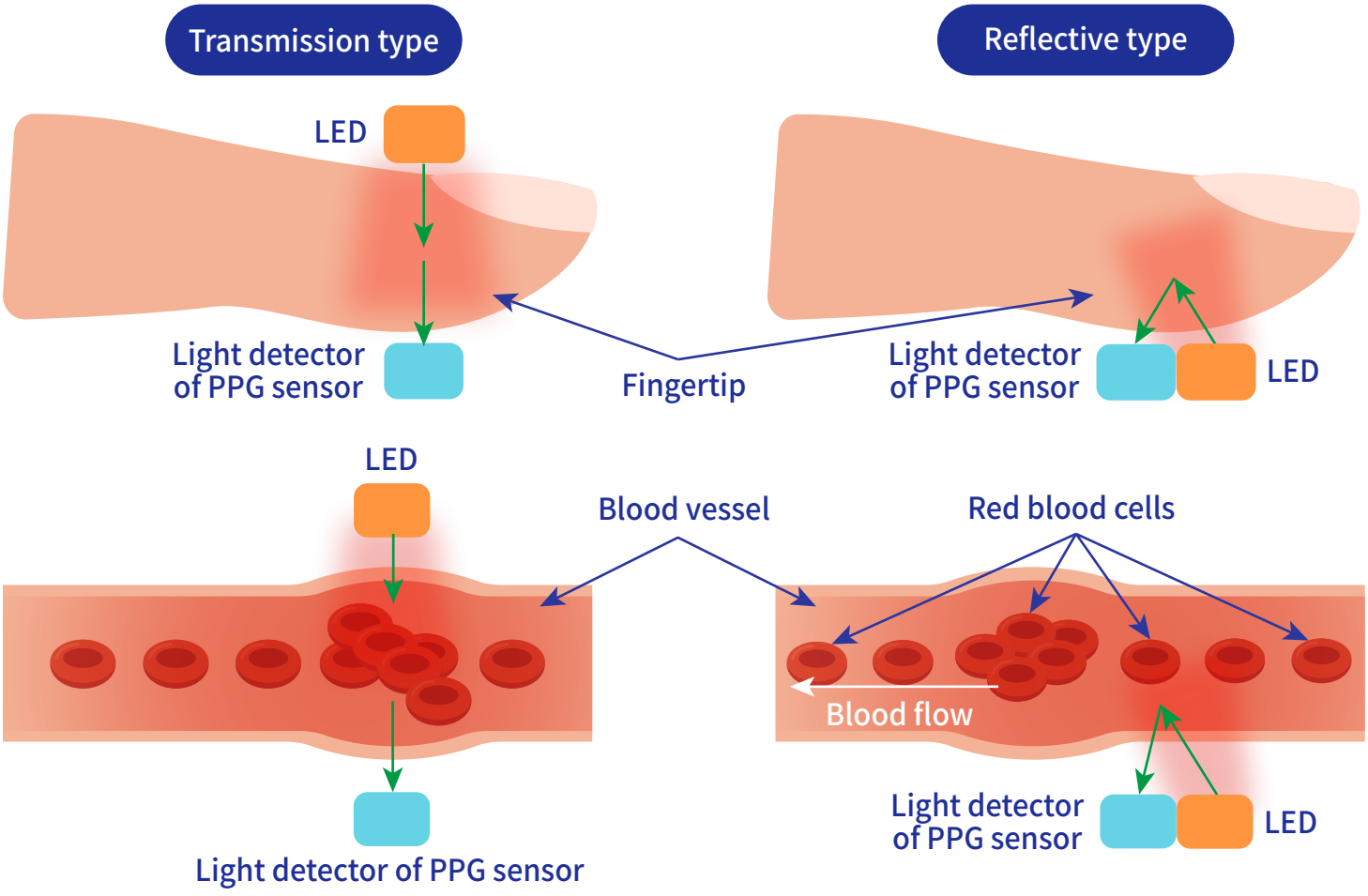
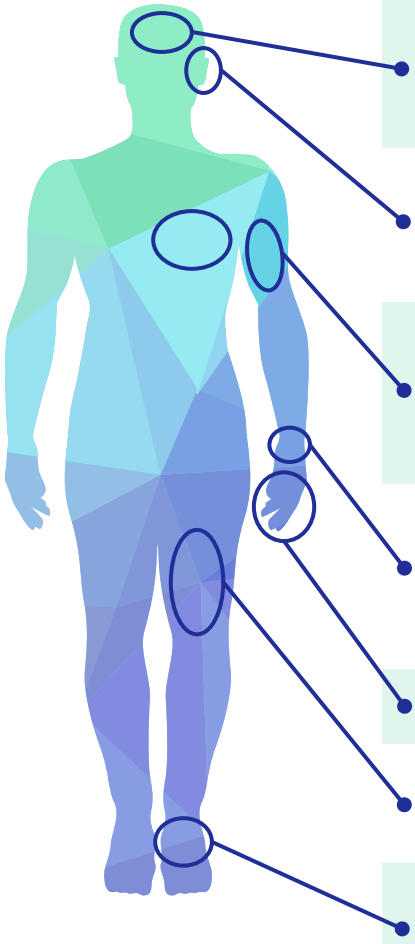


Fig. 4 Types of PPG Detection: the transmission type (left) and the reflective type (right).



Body location	Remarks
Forehead	A good place for pulse rate measurement because the relative motion is small, but not suitable for long-term or continuous monitoring.
Ear	One of the best places for biometric measurements, but not suitable for long term or continuous monitoring.
Arm and Chest	The arms and chest are good for long-term monitoring. This area will experience more relative motion than head, but large blood flow can give a better signal.
Wrist	A most popular but yet hardest location for measurements. Wrist is filled with tendons and ligaments that scatter light significantly. This location is also highly sensitive to motion noise.
Fingertip	Another most popular location.
Calf and Quad	This is a good area for signal measurements when not walking or running.
Ankle	Very difficult for biometric signal measurements as it contains numerous tendons and ligaments of limited blood flow.

Fig. 5 Common body locations for PPG Sensor

Questions

1 Why **green** or **red** LEDs are usually used to detect blood volume in PPG?

Instructions

Watch the video for a demonstration of pulse measurement using DIY pulse sensor.

Video 13

Fig. 6
DIY pulse sensor

Configure the oscilloscope as shown in the video. Gently put your finger on the active area of the pulse sensor (Fig. 6) and observe the pulse wave on the oscilloscope.

Results

Take a photo of your pulse wave and paste it in the space below.

Calculation of pulse rate

Fig. 7 shows a typical pulse wave. The pulse rate can be calculated by:

$$\text{Pulse rate (pulses per minute)} = \frac{1}{\text{Time interval between cardiac cycles (second)}} \times 60$$

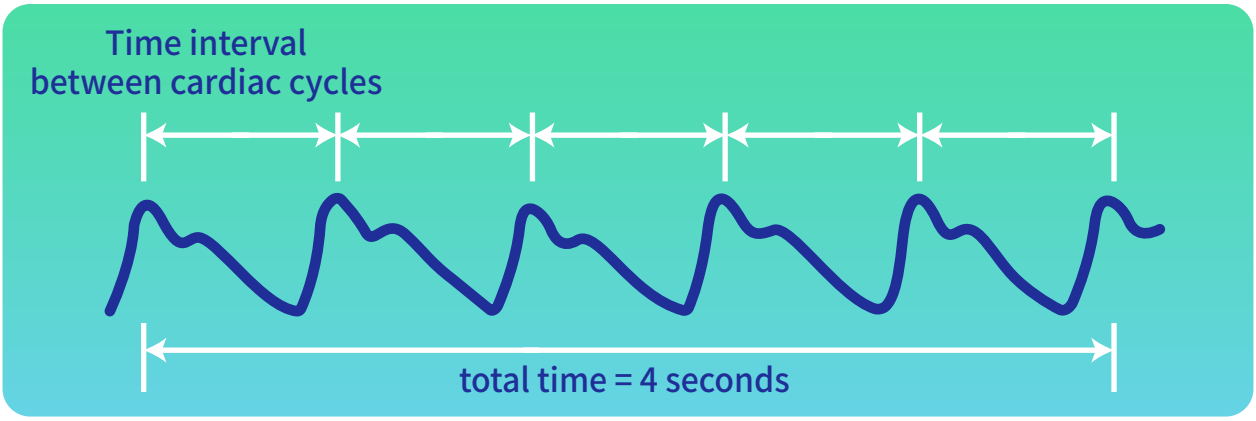


Fig. 7 A pulse wave indicating 5 complete cardiac cycles.

Therefore, by measuring the time interval between 2 or more cardiac cycles (or pulses)*, the pulse rate can be estimated.

For example in Fig. 7, the total time interval for 5 cardiac cycles (pulses) is 4 seconds, the pulse rate is

$$\frac{1}{4 \div 5} \times 60 = 75 \text{ pulses per minute}$$

*Remark: To avoid error which may be arisen from single abnormal time interval, we should count the time interval between several cardiac cycles (or pulses).

Questions

2 Based on the acquired pulse wave, calculate your pulse rate. Show your calculation.

3 Why should we monitor our pulse rate regularly?

Conclusion

- Heart contractions produce an increased blood volume in arteries, whereas heart relaxations produce a decreased blood volume.
- Photoplethysmography (PPG) is an optical method for detecting blood volume changes through a light beam (emitted by a green, red or infrared LED) either passing through or being reflected by the volume of blood, thus allowing the estimation of pulse rate.

Activity II
Effect of exercise on pulse rate

Introduction

In this activity, we will investigate the effects of exercise on the pulse rate.

Instructions

Follow a sequence of actions listed in Table 1, measure your pulse rate using the DIY pulse sensor after each, and see whether your pulse rhythm shown on the oscilloscope is regular.

Results

	Action	Pulse rate (pulses per minute)	Is the pulse rhythm regular?
1	Taking rest (i.e. sit on a chair for 1 minute)		
	Remain at rest and measure **pulse rate 1.**		Yes / No
2	Exercise for around 1 minute (Choose one: Jogging / Walking up and down a step / Jumping vertically for 10 times / Others: _____)		
	Immediately after exercise, measure **pulse rate 2.**		Yes / No
3	Taking rest after exercise (stand and relax for 1 minute)		
	After taking a rest, measure **pulse rate 3.**		Yes / No

Table 1

Questions

4 Compare pulse rates 1 and 2 in Table 1. Did your pulse rate increase or decrease after the exercise?

5 An increased pulse rate indicates that the heart contracts and relaxes more frequently. Why does the heart rate increase during exercise?

6 Compare pulse rates 1 and 3 in Table 1. Which one is higher? What is the significance of this phenomenon? (Hint: oxygen debt*)

* An oxygen debt refers to the extra amount of oxygen needed (after exercise) for removing the lactic acid produced in muscle cells during anaerobic respiration.

Conclusion

- Heart contracts and relaxes at a higher rate during exercise and after exercise to help supply additional oxygen and nutrients to muscles and body cells and, at the same time, removing carbon dioxide and lactic acid from them.
- The technology of photoplethysmography (PPG) is widely adopted in wearable devices such as smartwatches so that people can monitor their pulse rates during and after exercise in a convenient way.