Lab 4: The Human Cardiovascular System

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Section 04

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INTRODUCTION

The purpose of the lab four was to measure and record the properties of the cardiovascular system during rest, exercise that included measuring blood pressure under stress, postural changes; as well as observing the reflex and the baroreflex during diving in ice water.

Cardiovascular system is one of the most important system in human body, it provides nutrient and removes by-product from the body, and it helps the organ function properly. The heart creates pressure and pumps oxygenated blood through the systemic circulation and returns deoxygenated blood though the pulmonary circulation. Heart is consist of right atrium, right ventricle, left atrium, and left ventricle, the right and left side of heart work together to ensure blood to flow continuously to heart, lung, and the rest of the body. The oxygenated blood flows from pulmonary vein into the left atrium, and then blood flows to left ventricle through mitral valve, and mitral valve closes when ventricle is full, then the blood flows to the rest of body though aorta. The oxygen and wastes (Carbon dioxide) exchanges in microcirculation such as capillaries, which is the smallest vessel. The deoxygenated blood flows from right atrium to right ventricle, then flows to the pulmonary artery and to the lung. Exchanging occurs again though alveolar capillaries. Eventually, blood becomes oxygenated, which then travels back to pulmonary vein and return back to left atrium, and left ventricle. This process repeats as a blood flow cycle. (Sherwood, 2013, p 733) Previous studies have shown the change of human cardiovascular system with responses to postural changes, physical activities, and temperature changes. In part II, the study from Watanable indicated that sympathetic activity is initiated in tilt. (Watanabe, et al, 2007) Furthermore, temperature is considered to be a factor causing decrease of heart rate; when face immersed into cold water, activating parasympathetic input causing a decrease in heart rate. (Jay et al, 2006 p. 199) In addition, baroreceptor plays an
important role in arterial pressure, baroreceptor allows increase in sympathetic activity. (Malliani et al, 1997)

Part I of the lab was to practice measure and use the sphygmonmanometer. Part II of this study was to observe the effects of blood pressure due to the postural change. The subject was put from supine position to tilt position, her blood pressure should have a dramatically decrease due to immediately initial tilt, and then the blood pressure should increase and back to the baseline after two minutes. Similar results should also apply to pulse pressure, cardiac output, stroke volume, and total peripheral resistance, which would drop at the beginning, then back to the baseline. Also, the heart rate should decrease due to the decrease in venous return, as more time is needed to fill the ventricle before it can pump the blood out again. On the other hand, mean arterial pressure would be increase. In part III, vasodilation in response to metabolites would be observed and it is expected when the arm is cuffed, the arm will change in color and temperature but return to normal once the cuff is removed. In part IV, the experiment is tested on different properties of the venous system, the hypothesis is that the raised arm would have changes on color and temperature; there will be a pressure different when the veins are all collapsed; the vein would bulged when occluded a vein away from the heart; and inflation of a cuff on the bicep to observe an increase of circumference. In the part V of this lab, the subject was asked to ride bike with increase work load from 0 to 2 kPa. The researcher expected the increasing metabolic activity should correspond to an increase in heart rate, pulse pressure, and stroke volume, leading to an increase in cardiac output and a decrease in total peripheral resistance. In the last part of this lab was to observe the dive reflex by having a subject hold her breath in ice water, and it’s expected that her heart rate will decrease.
MATERIALS AND METHODS

Specific detail of procedure can be found in NPB 101L: Systemic Physiology Lab Manual (Bautista et al., 2009, p.31-40). There were six parts of this lab, in Part I, students practiced to use sphygmomanometer which is the blood pressure cuff, inflating the cuff to 180mmHg and slowly releasing the pressure till heard first beat which was systolic pressure, and the last beat was diastolic pressure. In Part II: the subject was put in a supine position and tilted, the blood pressure of both arm was recorded. Biopac was used to measure heart rate, it was determined using an average of ten beats. In part III of this lab, extending subject’s left arm above the head and clenching around 15 times, then hold a tight fist. Inflating the subject’s arm to 150 mmHg for less than 30s, then ripping it off; recording and comparing. In part IV, the subject held his arm above his head for one minute and then returned his arms on the table for observations of gravity and venous congestion; in next section, the subject held one arm above his head and lifted slowly and observed if the vein is collapsed; moreover, the subject’s arm was cuffed to 40 mmHg, then occluded a prominent vein and push the same vein toward heart and again away from the heart. In part V: heart activity was recorded by Biopac while subject was pedaling on exercise bike at a constant rate, and work load was added by 0.5 kPa from 0 to 2 kPa. Heart rate was calculated from average of ten beats. In part VI, the subject held her breath above ice water for 30s and the put her face into water as long as possible. Record the heart rate.

In part I, Recording blood pressure three times per person was omitted from this report. And in part II, it was TA turned the subject from supine position to tilt position, which was different from lab manual. In the part V, the P-T interval calculation has been excluded from this report.
RESULTS

Part I: Blood Pressure Measurements

For this part, group members practiced to measure blood pressure by using sphygmomanometer, which is the blood pressure cuff.

Part II: Effects of Posture on Blood Pressure

Table 1 data table for tilt exercise

<table>
<thead>
<tr>
<th></th>
<th>Blood Pressure (systolic/diastolic)</th>
<th>MAP</th>
<th>PP</th>
<th>HR</th>
<th>SV</th>
<th>CO</th>
<th>TPR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right Arm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supine</td>
<td>112/64</td>
<td>112/66</td>
<td>112/65</td>
<td>80.7</td>
<td>47</td>
<td>66</td>
<td>70.5</td>
</tr>
<tr>
<td>Initial Tilt</td>
<td>104/68</td>
<td>106/68</td>
<td>105/68</td>
<td>80.3</td>
<td>37</td>
<td>71</td>
<td>55.5</td>
</tr>
<tr>
<td>30 sec post-tilt</td>
<td>110/66</td>
<td>110/66</td>
<td>110/66</td>
<td>80.7</td>
<td>44</td>
<td>69</td>
<td>66</td>
</tr>
<tr>
<td>2 min post-tilt</td>
<td>114/66</td>
<td>112/66</td>
<td>113/66</td>
<td>81.7</td>
<td>47</td>
<td>76</td>
<td>70.5</td>
</tr>
</tbody>
</table>

After the tile, systolic pressure decreased from 112 mmHg to 105 mmHg, and diastolic pressure increased from 65 to 68, as indicated in Figure 1. Diastolic pressure increased from 105 mmHg to 110 mmHg following thirty seconds post tilt while systolic pressure dropped from 68 mmHg to 65 mmHg.
Figure 1: Graphic representation of Systolic and Diastolic blood pressures versus time. Supine blood pressure showed in 315 seconds, Initial tilt blood pressure showed in 408, 30 seconds post-tilt blood pressure showed in 453, and 2 minutes post tilt blood pressure showed 563 seconds.

As shown in Figure 2, MAP had significant drop from supine position to initial tilt blood pressure. At 30 second post-tilt pressure, it increased to 80.7 mmHg which was same as supine blood pressure, and then it continued to increase 1.4 mmHg to the 81.7 mmHg. Overall, mean arterial pressure increased 1.0 mmHg.
Figure 2: Graphic representation of Mean Arterial Pressures versus time. Supine blood pressure showed in 315 seconds, Initial tilt blood pressure showed in 408, 30 seconds post-tilt blood pressure showed in 453, and 2 minutes post tilt blood pressure showed 563 seconds.

Similar to Figure 2, Pulse Pressure of figure 3 presented a decrease of 10 mmHg from supine position to initial tilt, then it increased a little following by both 30 second and 2 minutes post tilt, as seen in figure 3.

Figure 3: Graphic representation of Pulse Pressures versus time. Supine blood pressure showed in 315 seconds, Initial tilt blood pressure showed in 408, 30 seconds post-tilt blood pressure showed in 453, and 2 minutes post tilt blood pressure showed 563 seconds.

As seen in the data from BioPac program, the heart rate initially increased from supine position (66 BPM) to initial tilt (71 BPM), then it decreased at thirty second post tilt (69 BPM), at the end, it became 76 BPM at two minutes post-tilt, as shown in Figure 4. Overall, the heart rate increased 10 BPM.
The Stroke Volume was decreased from Supine position measurement to initial tilt, and then it increased from 55.5 ml to 66ml, finally, stroke volume lightly increased from thirty second post tilt to two minute post tilt, as shown in figure 5.
The cardiac output decreased between the time of supine position and the initial tilt, with an increase between the initial tilt and thirty second post tilt, with approximately 614 ml increased. And the cardiac Output kept increasing from 4554ml to 5458ml, which is the highest point, as shown in figure 6.

The total peripheral resistance increased at first where supine position (0.0173 mmHg*ml/min) and initial tilt position (0.0204 mmHg*ml/min), however, it decreased to 0.0177 mmHg*ml/min at thirty second tilt position, and finally it reached 0.0152 mmHg*ml/min) at two minutes tilt position, as seen in figure 7. Overall, TPR increased 0.0031 mmHg*ml/min, but decreased 0.0052 mmHg*ml/min.
Figure 7: Graphic representation of Total peripheral resistance versus time. Supine blood pressure showed in 315 seconds, Initial tilt blood pressure showed in 408, 30 seconds post-tilt blood pressure showed in 453, and 2 minutes post tilt blood pressure showed 563 seconds.

Part III: Vasodilation in response to Exercise

The subject was 24-year-old male. Before placing the blood pressure cuff around the arm of him, both of his hands were white and slightly distended veins. After extended his hand above the head, clenched hand, and inflated the cuff around his arm to 150mmHg, two hands showed noticeably different characteristics when both hands were placed on the bench. The left arm was visibly paler than the right arm, and noticeably cooler. Also the veins were less distended than they were before.

Part IV: Venous System

Gravity and Venous Congestion: the subject was a 20-year-old male. With hanging his left arm above his head, and comparing with the right hand, the left hand was paler and cooler which lasted about 20 second; the veins were less distended, and tingly fingertips as the subject described. And the right arm was pinker, warmer, and had more distended veins.
Venous Return: The veins of the hand which being slowly lifted collapsed 12cm above the level of approximate heart height. Since 1.36cm=1mmHg, it’s equivalent to 8.83mmHg.

The Valves in the Vein: after inflate to 40 mmHg, occluded a prominent vein and push the same vein toward heart and again away from the heart. The veins collapsed when the occluded blood was pushed towards the heart; and then vein was bulged when the occluded blood was pushed away from the heart.

Venous Distention: As the pressure increased, the circumference of the arm was increased as well. As shown in figure 8, the circumference had a significant increase (1.2%) as increase of cuff pressure, from 16.5cm to 18.5cm with pressure increase from 0 to 60 mmHg.

![Circumference vs. Cuff Pressure](image)

**Figure 8**: Graphic representation of circumference of the left forearm as increase of pressure.

Part V: Cardiovascular Responses to Exercise

In this part, the subject was a 22-year-old female, and heart activity and blood pressure was measured with increase workload, blood pressure and heart rate was recorded and calculate MAP, PP, SV, CO, and TPR.

Table 2 Recorded Cardiovascular Parameters During Exercise
<table>
<thead>
<tr>
<th>Work Load (kPa)</th>
<th>PP</th>
<th>MAP</th>
<th>HR</th>
<th>SV</th>
<th>CO</th>
<th>TPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.5</td>
<td>30</td>
<td>90</td>
<td>76</td>
<td>37.5</td>
<td>2850</td>
<td>0.0316</td>
</tr>
<tr>
<td>0</td>
<td>50</td>
<td>86.7</td>
<td>103</td>
<td>62.5</td>
<td>6437.5</td>
<td>0.0135</td>
</tr>
<tr>
<td>0.5</td>
<td>47</td>
<td>92.7</td>
<td>104</td>
<td>58.8</td>
<td>6110</td>
<td>0.0152</td>
</tr>
<tr>
<td>1</td>
<td>51</td>
<td>95.0</td>
<td>130</td>
<td>63.8</td>
<td>8287.5</td>
<td>0.0115</td>
</tr>
<tr>
<td>1.5</td>
<td>53</td>
<td>102.7</td>
<td>146</td>
<td>66.3</td>
<td>9672.5</td>
<td>0.0106</td>
</tr>
<tr>
<td>2</td>
<td>65</td>
<td>99.7</td>
<td>166</td>
<td>81.3</td>
<td>13487.5</td>
<td>0.0074</td>
</tr>
</tbody>
</table>

The subject’s mean arterial pressure went down from rest to 0 work load of 4 mmHg, and then continuous increased from 0 to 1.5 kPa work load, however, with a sharp decline in MAP values at 2.0 kPa with the value of 99.6 mmHg.

**Figure 9:** Graphic representation of Mean Arterial Pressure versus a increase of workload, with -0.5 kPa representing values obtained at rest. Each value was determined while the subject pedaled at a rate of approximately 50rpm.

Pulse Pressure showed a consistent increase with the increase of work load. At rest, the PP was 30 mmHg, and was increased to 65 mmHg, this is a 54% increase in pressure.
Stroke Volume showed a continuous increase with the increase of work load, overall, the stroke volume increased from 37.5 mmHg to 81.2 mmHg.

**Figure 10:** Graphic representation of Pulse Pressure versus a increase of workload, with -0.5 kPa representing values obtained at rest. Each value was determined while the subject pedaled at a rate of approximately 50 rpm.

**Figure 11:** Graphic representation of Stroke Volume versus a increase of workload, with -0.5 kPa representing values obtained at rest. Each value was determined while the subject pedaled at a rate of approximately 50 rpm.
Cardiac output overall shown a continuous increase with the increase of work load, but there was a slightly drop from 0 to 0.5 kPa work load and it went from 6437.5 ml/min to 6110 ml/min. Then it reached 13287.5 ml/min at work load was 2 kPa.

**Figure 12:** Graphic representation of Cardio Output versus a increase of workload, with -0.5kPa representing values obtained at rest. Each value was determined while the subject pedaled at a rate of approximately 50rpm.

Heart rate displayed a consistent and almost linear increase, which means the increase rate were similar from rest to 2 kPa work load.
**Figure 13:** Graphic representation of Heart rate versus a increase of workload, with -0.5kPa representing values obtained at rest. Each value was determined while the subject pedaled at a rate of approximately 50rpm.

The highest value of TPR was at rest and then showed a linear decrease as the work load increased, the most significant drop happened between rest to 0.

![TPR vs. Work load](image)

**Figure 14:** Graphic representation of total peripheral resistance versus a increase of workload, with -0.5kPa representing values obtained at rest. Each value was determined while the subject pedaled at a rate of approximately 50rpm.

**Part VI: The Dive Reflex**

The subject was 24-year-old female. As seen in figure 14, heart rate in water versus time is measured by electrocardiogram, which calculates heart rate. Her resting hart rate was 97 BPM, when she held breath above water, her heart rate decrease to minimum at 72 BPM, then there was an increase to 80 BPM, Figure 15 described the heart rate of subject holding her breath with face in ice cold water, there was a significant decrease from 114 BPM to 51 BPM, but there was a small boom of 62 BPM at 45s.
DISCUSSION

The Human cardiovascular system is a pump system that provides nutrients and removes wastes from the body. The blood flows down its pressure gradient, transporting from the area of highest pressure in the heart to the area of lowest pressure. The heart consists of four chambers: the right atrium, where the deoxygenated blood enters through the Vena Cave; the right ventricle,
where the deoxygenated blood from the atrium is plumed to the lungs through the left pulmonary artery; the left atrium, where oxygenated blood from the right atrium is pumped to the lungs through the left pulmonary artery; the left atrium, where oxygenated blood from right atrium is pumped to the rest of the body through the aorta. As blood enters the chamber, it go into right ventricle through the tricuspid valve at low pressure, during diastole, approximately 80% of atrium’s volume flows in to right ventricle, then the right atrium is depolarized, and eject the rest of blood from right atrium to the right ventricle through the tricuspid valve. Action potentials then continue to stimulate from SA nod to AV node, but AV nodal delay will ensure adequate ventricular filling from atrial systole. Moreover, the action potential move down to the AV bundle, through the left and right bundle branches in the ventricular septum, and will radiate to the apex of the ventricle and outward, initiating ventricular systole. (Sherwood, 2013, p 752) Furthermore, the central venous pressure is the blood pressure in the vena cave; it is the major role of filling pressure therefore the preload of the right ventricle, which regulates stroke volume, it could be influenced by heart rate, cardiac output. The MAP increase when the central venous pressure increase. (Gelman, 2008, p 4, 9)

In part II of this lab, it was studied the effect on blood pressure due to postural changes as the subject was asked to be supine position for five minutes and then immediately turned to be tilted position. Blood pressure changed during postural changing, it went down from 112/65 mmHg at supine to 105/68 mmHg at initial tilt position, as seen in Figure 1, this significant decrease at the beginning was due to gravity acting on arterial flow which made venous return decreased, blood pools in the lower body and decreased in the amount of blood that is pumped out of the heart and into the body, which also caused immediate decrease in mean arterial pressure (Figure 2), pulse pressure (Figure3), stroke volume (Figure 5) and cardiac output
(Figure 6), as predicted. The mean arterial pressure factored systolic and diastolic pressure of the cardiovascular system, controlled and regulated by baroreceptors. The baroreceptor reflex, which firing rate decreases and baroreceptor reflexes act to help restore blood pressure by increase heart rate (Figure 4), it maintain the stable of blood pressure. (Malliani et al, 1997) As observed, the blood pressure, pulse pressure, cardiac output, and stoke volume increased back to baseline, as predicted. Because the baroreceptor reflex increased sympathetic activity, which initiated a global vasoconstriction, thereby increasing mean arterial pressure and cardiac output with an decrease in total peripheral resistance (Figure 7). This effect would drive blood away from the lower extremities towards the heart. (Sherwood, 2013, p 908) Similar results can be found in the Literature, the initial pooling leads to the drop in systolic pressure and venous return, so the stroke volume decreased. The signals from aortic arch and carotid sinus caused baroreceptors firing less and initiating an increase of sympathetic activity, then increasing diastolic pressure, vasoconstriction, and heart rate, which led to increase in MAP and PP. (Lanfranchi et al. 2002, p R315) Last but not the least, heart rate was calculated from ECG data, the P wave corresponded to atrial depolarization, the QRS wave corresponded to the ventricular depolarization, and T wave corresponded to the ventricular repolarization. However, as seen in figure 4, heart rate increased from 66BPM to 71BPM, this didn’t satisfy the expectation might because the subject was nervous when taking the test.

In part III, the exercise introduced reactive hyperemia via by the cuff that inflated the arm to 150mmHg. When the cuff was inflated after clenching the fist repeatedly, the arm turned to paler, cooler, and the veins were not visible as they were before, as predicted. The arm back to normal in 2-3 second after the cuff removed, this is because the fact that the cuff blocks the
vessels that flow to the upper arm, therefore, the blood abruptly returns to the arm causing the arm back to normal appearance after removing the cuff.

The results observed in part II could also be observed in part IV *Gravity and Venous Congestion*, the venous distention as a result of increase of central venous pressure in one arm induced by holding the other arm above the head for one minutes. The blood of the elevated left arm flowed down into lower body and the right arm. The right arm was pinker, warmer, and had more distended veins due to the increase in blood flow in that region. The reason for the left hand was paler, cooler and less distended veins was that blood flow decreased due to elevation. Moreover, the lower pressure in the veins created a larger pressure gradient followed by the change of *Gravity and Venous Congestion*, and along with a small internal elastic lamina and layer of smooth muscle, the vein were highly collapse. In the *Venous Return* of this section, the same phenomena was presented, veins were collapsed when the subject held left arm above the head and slowly lift the other arm. Once his arm reached the area near his heart, the hydrostatic pressure was approximately zero, as the left arm continued raise, so the pressure continued to drop until the veins eventually collapsed, which was due to the decrease effect of gravitational potential energy being exerted on the blood in the arm. As a result, there was 12cm distance between heart and arm, which was equivalent 8.83mmHg pressure difference. There might be some experiential error such as the subject raised his arm too quick so that the distance was read inaccurately. In *The Valves in the Vein*, the blood was pushed toward heart after inflate to 40 mmHg, the veins were collapsed; and when the blood was pushed away from heart, the veins were bulged. This is because venous valves are uni-direction, which only allow blood to move towards the heart. While moving, skeletal muscle contacts and squeezes veins pushing blood in both directions, valves ensure blood complete the cycle back to the heart. (Sherwood, 2013, p.
In the Venous Distention, as the pressure increased, the circumference of the arm was increased as well, as seen in Figure 8, the overall increase of circumference was 2 cm (1.2%). Blood flows down from higher pressure arteries to lower pressure arteries, by pumping the cuff, blood flow was obstructed towards the heart by establishing a barrier on the superficial veins’ blood flow, the higher the pressure cuff, the more the circumference of the arm increased from the venous distention. The pressure of the cuff stayed lower than the arterial pressure, blood could still be delivered to the arm, but the blood pooled in arm as the cuff prevents normal blood flow back to the heart. Veins were able to hold the extra blood due to distension

In part V of this study, active hyperemia was observed, with the increasing of the metabolic activity work load, it was same as the expectation, there was a linear increase in heart rate (Figure 13) as work load increase which collected by BioPac program (10 second window of ECG attached in the appendix). The cardiac output was also increase as increase of heart rate and stable stroke volume. Active hyperemia causes vasodilation to increase blood flow due to an increased need for nutrients and waste removal from metabolically active cells. (Sherwood, 2013, p, 832) During exercise, cells had an increase need for oxygen and nutrients, causing an increase in blood uptake to meet these need, which caused decrease of blood pressure at the beginning, but as discussed before, it was the baroreceptor reflect brought blood pressure back (Figure 9). As shown in Figure 10 and Figure 11, both pulse pressure and stroke volume experienced a plateaued during 0 to 1.5 kPa work load, then they were increased on 2 kPa work load, this was as expected because the increase of sympathetic activity in heart, the AV nodal delay was decreased by increasing conduction velocity by enhancing the L-type Ca\(^{2+}\) chanel. The decrease in TPR is attributed to the substantial increase in the cardiac output, since TPR=MAP/CO.
In the last part of this experiment was to observe the dive reflex, unlike part II and part V, the dive reflex showed increase of parasympathetic activity and sympathetic activity when face was immersed in ice water. Comparing the control trial of holding subject’s breath above the water (figure 15) with the trial of holding her breath with her face immersed in ice water (figure 16), heart rate of both graph decreased, as expected, but the heart rate of control trial was from 97 BPM to 72 BPM, on the other hand, the heart rate of figure 16 had a range of 114 BPM to 51 BPM. ECG data of the subject showed noticeable bradycardia as her face was held above the water holding her breath but displayed an tachycardia when the face was immersed into water. Also while she holding her breath in the ice water, there was a skipped beat observed from ECG data (figure 17), 10-second window of ECG attached in the appendix. This is because high amount of parasympathetic input, resulting in vagal escape, which is prolonged vagal stimulation, would cause bradycardia and eventually cardiac arrest.

![Figure 17: ECG raw data during face immersion](image)

In the literature, this phenomenon has been studied and shown similar results as this report. A face immersion in cold water resulted in a slower heart rate and slower depletion of oxygen supply. (Jay et al., 2006, p.203) The Mammalian diving reflex, it was induced by bradycardia in response to submersion, where immediately upon facial contact with ice water, the heart rate dropped dramatically.
REFERENCE


Sample Calculation:

Given BP 112/65 at supine

MAP=1/3 (SP) + 2/3(DP) = 1/3 (112) + 2/3(65) = 80.7 mmHg

PP=SP-DP=112-65=47 mmHg

HR=an average of HR taken from Biopac: (84+81+78+74+67+72+80+82+75+64)/10 = 66 BPM

SV=PP* Arterial Distensibility=47*1.5(at rest)=70.5 ml

CO=SV*HR=70.5*66=4653 ml*min/ml= 5.653L/min

TPR= MAP/CO= 80.7/4563=0.0177mmHg/ml/min

Raw Data:

Supine

Initial Tilt
30 s Post-tilt

2 min post-tilt

Bike resting

0 kPa
Control breath holds start

Control breath hold stop

Dive reflex start

Dive reflex during
Dive reflect stop