Short-Term Cardiovascular Control
Facilitator’s Guide

Time to Complete
This activity is predicted to take about an hour, but will vary based on level of students and the number of times the facilitator intervenes in the activity. It will also vary based on modifications by the facilitator.

Prior Knowledge
- Definition of homeostasis.
- Components of a homeostatic feedback loop (sensors, integrator, effectors, controlled variable(s)).
- Relationship between mean arterial pressure (MAP), heart rate (HR), stroke volume (SV) and vascular resistance (VR).

Content Objectives/Learning Goals
Students will be able to:
1. Apply the relationships between MAP, HR, SV and VR in the context of rest and during exertion (exercise).
2. Identify HR as an effector in the control of MAP and not a controlled variable by itself.
3. Identify that just because a variable/value does not change, that it is not necessarily homeostatically controlled.

Implementation Notes for Instructors:
This is a more advanced activity that is best used to summarize how changes in blood pressure are regulated in the short term and to apply the concept of homeostatic feedback loops to this control. An additional goal is for students to identify that HR is not a homeostatically controlled variable – a common misconception; and that even if a “measured” variable stays constant, that it may not be homeostatically controlled. Instructors may wish to have regular team reports throughout the activity to assess student’s application and understanding of topics.

The activity generally works best in groups of 3-4 students and specific roles may be assigned to aid in completion of the activity. For example:
- Manager – keeps the team on task
- Reader – reads the questions to the group.
- Recorder – records “official” team answers
- Reporter – reports team answers when requested by the instructor

Instructors are encouraged to read through the entire activity and make adjustments based on their particular needs before making copies for their students. Open source images can be modified in Powerpoint, Word or other programs in order to add or subtract labels, depending on instructor wishes. Questions can be changed for modified to best suit the course.
- The source used to create the data table in model 1 (see image credits below) contains additional time points, indicating an increase in blood pressure over 3 minutes of exercise, which could be added and used to portray a central resetting of the blood pressure set point supported by some sources.
- Facilitators may or may not want to include the data related to femoral artery cross-sectional area in their activity, depending on whether or not they want to stress that just because some
Experimental variables do not change, they are not always homeostatically controlled variables. Removal of such data would require a change to a couple of the questions.

- Model 2 could be replaced with an image from a textbook or other proprietary source that you use for your course, as long as it is not shared outside of your own students.

Model and Image Credits


Full data table (see implementation notes) is:

<table>
<thead>
<tr>
<th>Experimental variables</th>
<th>Rest</th>
<th>10 s</th>
<th>20 s</th>
<th>30 s</th>
<th>60 s</th>
<th>120 s</th>
<th>180 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (beats/min)</td>
<td>76</td>
<td>82</td>
<td>82</td>
<td>86</td>
<td>86</td>
<td>96</td>
<td>108</td>
</tr>
<tr>
<td>Mean BP (mmHg)</td>
<td>91</td>
<td>90</td>
<td>93</td>
<td>92</td>
<td>93</td>
<td>101</td>
<td>103</td>
</tr>
<tr>
<td>Femoral artery blood flow (l/min)</td>
<td>0.29</td>
<td>1.54</td>
<td>1.5</td>
<td>1.59</td>
<td>1.69</td>
<td>2.12</td>
<td>2.85</td>
</tr>
<tr>
<td>Leg Vascular Conductance (ml/min/mmHg)</td>
<td>2.9</td>
<td>10.5</td>
<td>9.9</td>
<td>10.4</td>
<td>11.2</td>
<td>13.5</td>
<td>18.5</td>
</tr>
<tr>
<td>Cross sectional area of the femoral artery (mm²)</td>
<td>17.2</td>
<td>17.4</td>
<td>16.3</td>
<td>16.3</td>
<td>16.7</td>
<td>16.3</td>
<td>16</td>
</tr>
</tbody>
</table>

**Model 2:** Murray Jensen (own work) and may be used or modified for educational purposes.

**Figure 1:** Ron Gerrits (own work) and may be used or modified for educational purposes.
Short-Term Cardiovascular Control

Model 1. Research Data. In order to obtain data related to cardiovascular function during exercise, the following was collected from 10 healthy male volunteers at rest and at various time points (in seconds) after the initiation of short bouts of upright stationary bicycle exercise. Data is presented as mean values from the group.

<table>
<thead>
<tr>
<th>Experimental variables</th>
<th>Rest</th>
<th>10 s</th>
<th>20 s</th>
<th>30 s</th>
<th>60 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (beats/min)</td>
<td>76</td>
<td>82</td>
<td>82</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>Mean BP (mmHg)</td>
<td>91</td>
<td>90</td>
<td>93</td>
<td>92</td>
<td>93</td>
</tr>
<tr>
<td>Femoral artery blood flow (l/min) in one leg</td>
<td>0.29</td>
<td>1.54</td>
<td>1.5</td>
<td>1.59</td>
<td>1.69</td>
</tr>
<tr>
<td>Leg Vascular Conductance (ml/min/mmHg)</td>
<td>2.9</td>
<td>10.5</td>
<td>9.9</td>
<td>10.4</td>
<td>11.2</td>
</tr>
<tr>
<td>Cross sectional area of the femoral artery (mm²)</td>
<td>17.2</td>
<td>17.4</td>
<td>16.3</td>
<td>16.3</td>
<td>16.7</td>
</tr>
</tbody>
</table>

1. Over what time period (in minutes) was data collected during exercise?

   1 min

2. Complete the following table using the data from model 1.

<table>
<thead>
<tr>
<th>Change in value from rest to last measurement during exercise (show calculation)</th>
<th>HR</th>
<th>Mean BP</th>
<th>Femoral artery blood flow (FABF)</th>
<th>Leg vascular conductance</th>
<th>Cross sectional area of femoral artery (CSAFA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>86-76 = 10 bpm</td>
<td>2/91</td>
<td>1.4</td>
<td>8.3</td>
<td>-.5</td>
<td></td>
</tr>
<tr>
<td>Percent change in value from rest to last measurement during exercise (show calculation)</td>
<td>(10)/76 = 13%</td>
<td>2%</td>
<td>483%</td>
<td>286%</td>
<td>-3%</td>
</tr>
</tbody>
</table>

3. Rank the experimental variables from those that changed the least to those that changed the most on a percentage basis.

   \textit{FABF > Leg vascular conductance > HR > CSAFA > mean BP}

4. Which (if any) of the experimental variables would you predict to be homeostatically controlled variables? Provide reasoning for your answer(s). Continue on back if necessary.

   Answers will vary, but students should be able to point out that BP varied the least and is therefore likely to be controlled. They might also include HR with reasoning that it did not vary as much as the other variables.
Model 2: Structural Feedback Loop that Helps Control Short-Term Cardiovascular Function

5. Label those structures in model 2 that are involved in the short-term control of cardiovascular function (label as many as you can). Write directly on the model.

   Students may be able to label: SA node, ventricle, atria, aortic baroreceptor, carotid bodies (baroreceptors), brainstem, afferent neurons, efferent neurons (vagus nerve), adrenal medulla, blood vessel, epinephrine (possibly).

6. List the structures that you labeled on the model. Briefly describe the function of each.

   Answers will vary, but reasonable answers might be:
   Aortic baroreceptor: Sensor for blood pressure.
   Carotid baroreceptor: Sensor for blood pressure
   SA node: Sets the HR
   Ventricles: Contract to generate blood pressure
   Atria: Receive blood from veins
   Afferent neurons: Carry blood pressure information to brainstem.
   Efferent neurons: Carry information to SA node, ventricles and adrenal medulla to stimulate (or inhibit) them.
   Brainstem: Receive information from the afferent neurons and control output to the efferent neurons.
   Adrenal medulla: Release epinephrine when stimulated.
   Epinephrine: Stimulate an increase in HR.
   Blood vessels: Carry blood. May constrict when high levels of epinephrine present.
7. Figure 1 shows the general model of a homeostatic feedback loop. Categorized the structures/functions from the previous question into components of the loop. Are there any structures/functions listed in the previous question that are not part of the loop?

Answers will vary, but reasonable answers might be:
Variable = blood pressure
Aortic baroreceptor: Sensor for blood pressure.
Carotid baroreceptor: Sensor for blood pressure
SA node: Effector structure that affects HR
Ventricles: Effectors that impact stroke volume/force of contraction.
Afferent neurons: Information flow.
Efferent neurons: Information flow.
Brainstem: Integrator.
Adrenal medulla: Effector organ that releases epinephrine.
Epinephrine: Information flow.
Blood vessels: Effector organ that impacts vascular resistance.

8. What information travels from the structures in model 2 to the brainstem? Does any of this information come directly from the heart?

Blood pressure, which is not measured in the heart.

9. There is both sympathetic and parasympathetic innervation to the heart. How does stimulation from these two types of innervation effect heart rate, stroke volume and blood pressure (if at all)? What are the mechanisms by which such changes are effected?

Sympathetic increases HR, parasympathetic decreases HR.
Sympathetic increases SV, parasympathetic has little impact on SV.
Sympathetic tends to increase BP via increased HR, SV and vascular resistance.
Parasympathetic tends to decrease BP via decreased HR.
10. Develop a 2 or 3 sentence explanation how heart rate is regulated.

The brainstem receives information from the baroreceptors, which measure BP. If BP is high, the brainstem slows HR via parasympathetic innervation. If BP is low, HR increases through sympathetic stimulation.

11. Develop a 2 or 3 sentence explanation as to how blood pressure is regulated.

Blood pressure is regulated through a combination of HR, SV and vascular resistance. If BP is low, one or more of these will increase. If BP is low, one or more of these will decrease.

12. Considering HR and BP, which would be considered a homeostatically controlled variable (neither, both, HR or BP)? Use data from model 1, and diagrams in model 2 and figure 1 to help support your answer. If you identify that one, or both of these variables is not a homeostatically controlled variable, comment on its role.

BP is homeostatically controlled. There are sensors for it, and it varies little during 1 minute of exercise. HR is an effector that helps control BP. There is no direct sensor for BP and it varies more than BP. Over longer duration exercise, it can vary significantly.

Extension/Challenge Questions:

13. Referring back to model 1, what happens to blood flow into the legs during bicycle exercise? Explain/predict what happens to cardiac output during this same time.

It increases significantly. Cardiac output would be expected to increase significantly to match the increased blood flow needs to the legs.

14. Assuming a resting cardiac output of 5 L/min and that any additional increase in CO with exercise is supplied to the legs, what happens to stroke volume between rest and 60s?

At rest: 5000 ml/min / 76 bpm = 66 ml/beat

During exercise: CO increases from 290 ml/min to 1,690 ml/min in one leg, for an increase of 1,400 ml/min in one leg or 2,800 ml/min in 2 legs. This provides an estimated cardiac output of 7,800 ml/min at 60 sec.

7,800 ml/min / 86 bpm = 91 ml/beat.

15. Write an equation that shows the relationship between mean blood pressure and cardiac output. Hint: The equation needs to contain at least one other variable.

Mean pressure = cardiac output x vascular resistance.
16. What happens to vascular resistance in the legs during bicycle exercise? Comment on how the data for both leg vascular conductance and femoral artery cross-sectional area either support, or do not support your conclusion about vascular resistance in the legs. Explain any discrepancies.

Resistance decreases significantly, as indicated by the large increase in leg vascular conductance (ml/min/mmHg). Because mean pressure did not change much and blood flow to the legs increased significantly, vascular resistance in the legs must have decreased.

Femoral artery cross-sectional area did not change. This may be counterintuitive, but this is a large conduit artery (similar to the aorta) that does not change its diameter much. Most resistance is due to the arterioles branching off of the femoral artery, which must dilate significantly to decrease the series vascular resistance in the legs.

17. Would you define the femoral artery cross-sectional area as a homeostatically controlled variable? Why or why not?

No, even though it did not change, there is no sensor for this variable. It doesn’t change because of its structural properties.

18. Using the following figure as a starting point, redraw it to show the response to exercise illustrated in model 1. It may be helpful to realize that this data was not measured continuously, but at specific time points. Consider the original stimulus to be exercise that induces a large change in leg vascular conductance (as supported by data in Model 1).

Stimulus = exercise causing decreased vascular resistance in the legs. This can cause a decrease in mean BP in the short term (not captured well in the data table). Lowered blood pressure is sensed by baroreceptors, fed to the brainstem which responds with increased HR and SV (CO) as a way to maintain blood pressure.