

16.423 Space Biomedical Engineering and Life Support Cardiovascular Adaptation to Microgravity

A series of pre-flight physiologic tests were performed on astronaut J.B. One test was the so-called “stand test”, in which the subject was asked to rise quickly from a supine to a standing position, and to remain standing quietly for 15–20 minutes (Figure 1). The electrocardiogram and arterial blood pressure were continuously monitored.

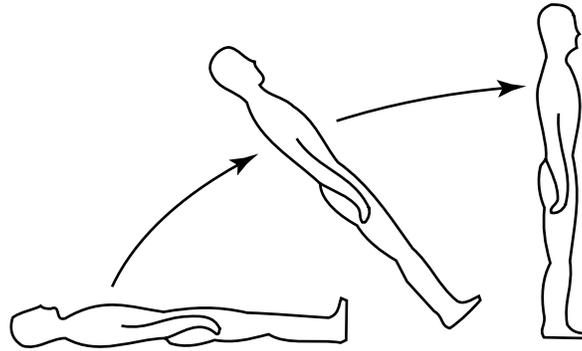


Figure 1:

A *theoretical* stand test is shown in Figure 2 for the case in which there are **NO** operational control systems. Heart rate and BP are plotted as functions of time for a short baseline period (lying) and the first 2 minutes after standing. The time of the change in posture is $t = 0$.

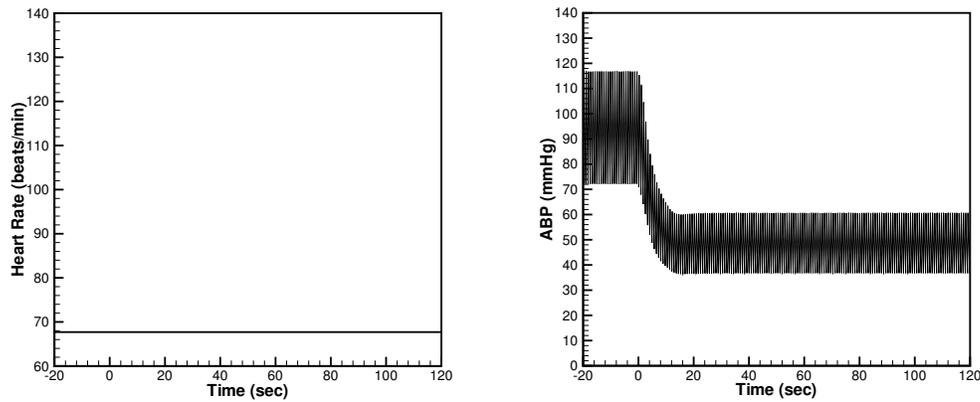


Figure 2: HR and BP in stand test—no CV controls

1. Compare the heart rate and blood pressure at time = +100 sec to the baseline values at time = -10 sec. What is the physiologic basis for the observed change in arterial BP?
2. The curves in Figure 3 show the patient's status at time = -10 sec. Using the axes provided, sketch CO/VR curves and a LV P-V loop to represent the hemodynamics at time = +100 sec. (Hint: First estimate the new CO assuming constant peripheral resistance.)

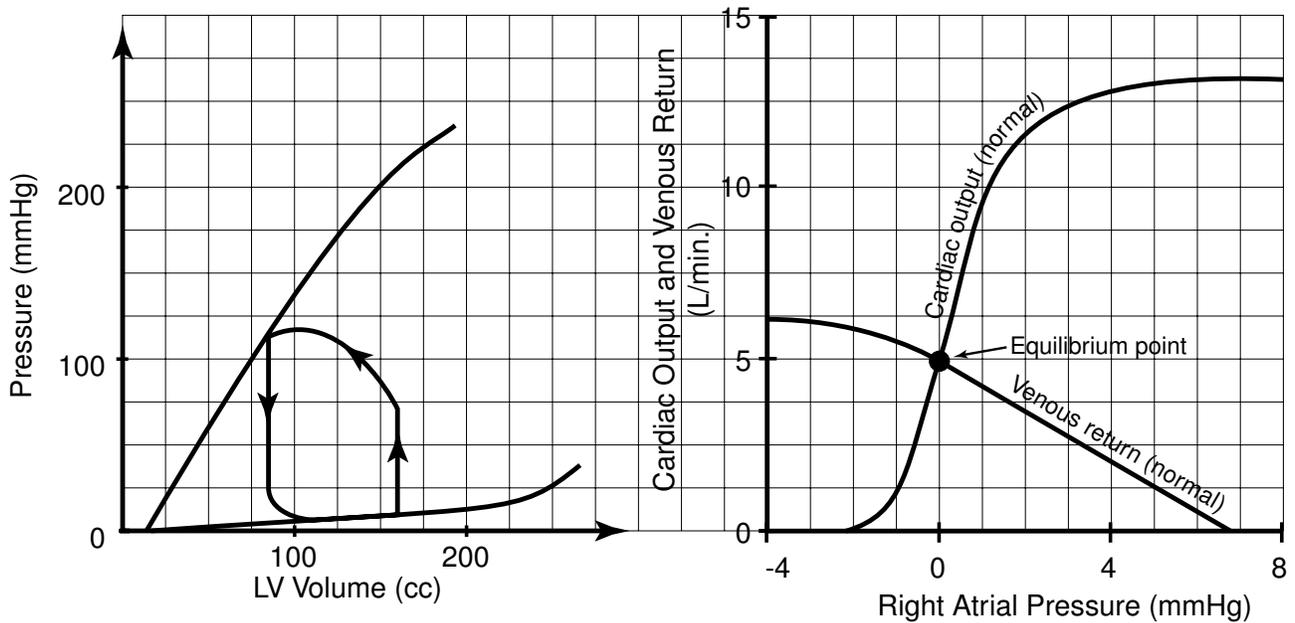


Figure 3: Cardiac output-venous return curves; LV pressure volume loops

Figure 4 shows the actual response observed in J.B. who has a normally functioning cardiovascular control system. Notice that the initial dip in BP occurs at $t \approx 8$ sec, the HR maximum occurs at $t \approx 12$ sec, and steady state is reached at about 100 seconds after standing. The mean BP when standing is very slightly higher than the control (lying) level.

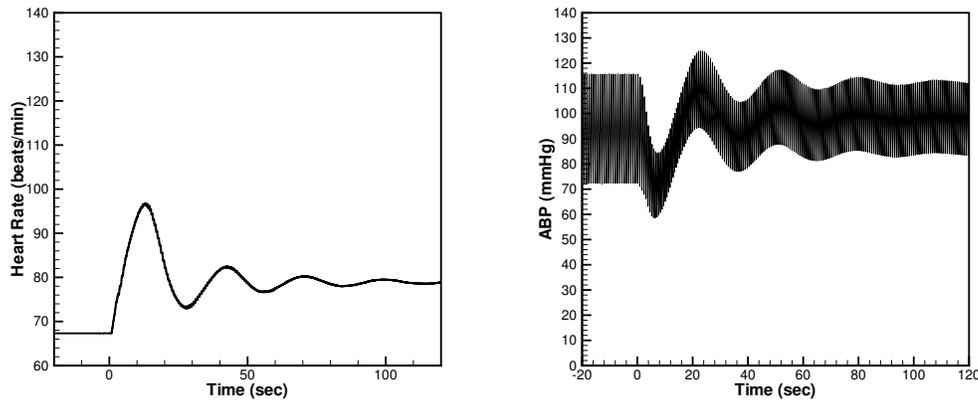


Figure 4: HR and BP in pre-flight stand test—intact CV controls

3. *What sensors and effectors are responsible for the behavior of heart rate and BP in Figure 4? What is the primary effector mechanism responsible for the initial increase in HR?*
4. *Why is the mean BP at 100 seconds slightly higher than the control level? (You may use the approximation $P_m = P_d + \frac{1}{3}(P_s - P_d)$.)*
5. *Using the axes of Figure 3 sketch the new situation at $t = 100$ sec. Demonstrate the expected impact of the control mechanisms by appropriately modifying the curves. Hint: Estimate the new CO by assuming that stroke volume is proportional to pulse pressure (systolic–diastolic ABP). Fill in the work sheet below as a guide to drawing the curves.*

Work Sheet

Parameter	$t = -10$ sec	$t = 100$ sec
HR		
CO		
SV		
Pulse Press.		
Mean ABP		

JB and his fellow astronauts blast off for the international space station, and quickly find themselves in zero-gravity. Within a very short time they begin to feel that their faces are bloated, and in fact they can observe that their faces seem to be somewhat swollen.

6. What shifts of blood volume would you expect in the early hours of weightlessness? Explain your rationale.

The mission ended after a total of 30 days, and the crew shuttled back to earth with no additional problems.

Immediately after landing a repeat stand test was performed on JB. The results are shown in Figure 5. Although JB was able to stand for the two minutes shown in the figure, he was not able to remain standing for more than five minutes. He became lightheaded and had to lie down to avoid fainting. (This difficulty of “postural hypotension” is a major problem in astronauts returning to earth from zero gravity.)

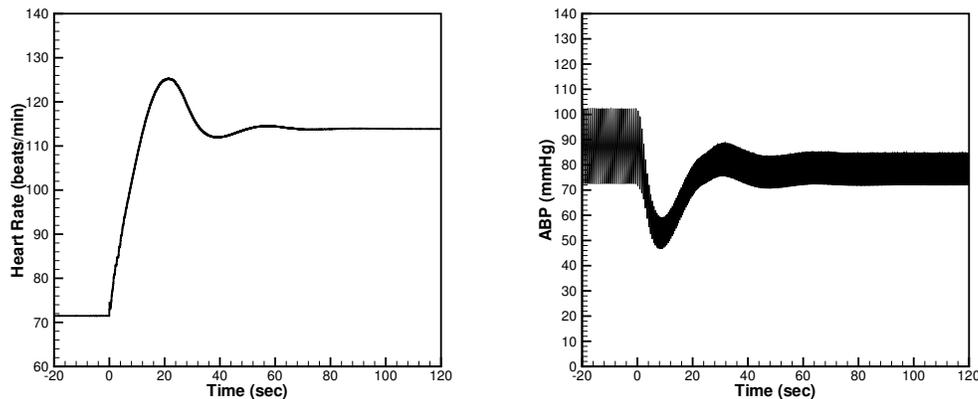


Figure 5: HR and BP in post-flight stand test—intact controls

Compared to the pre-flight stand test, the post-flight data shows a much more dramatic increase in heart rate, both transiently and at 100 seconds. Furthermore, the mean BP could not be maintained at the control level.

7. Why is the post-flight stand test result different from the pre-flight result?

8. Can you think of any countermeasures to reduce the problem of orthostatic hypotension? (Consider mechanical, pharmacological, or other methods.)