Modeling and Simulation of the Cardiovascular System – Michel Kana, PhD SS2010

Task is to model each equation in a single subsystem and put all subsystems together in a Simulink model.

Conservation of Mass at Pulmonary Arteries

$$\frac{dP_{pa}}{dt} = \frac{1}{C_{pa}}\left(F_{o,r} - F_{pa}\right) \tag{A1.1}$$

Balance of Forces at Pulmonary Arteries

$$\frac{dF_{pa}}{dt} = \frac{1}{L_{pa}}\left(P_{pa} - P_{pp} - R_{pa} \times F_{pa}\right) \tag{A1.2}$$

Conservation of Mass at Pulmonary Peripheral Circulation

$$\frac{dP_{pp}}{dt} = \frac{1}{C_{pp}}(F_{pa} - \frac{P_{pp} - P_{pv}}{R_{pp}}) \tag{A1.3}$$

Conservation of Mass at Pulmonary Veins

$$\frac{dP_{pv}}{dt} = \frac{1}{C_{pv}}\left(\frac{P_{pp} - P_{pv}}{R_{pp}} - \frac{P_{pv} - P_{la}}{R_{pv}}\right) \tag{A1.4}$$

Conservation of Mass at Systemic Arteries

$$\frac{dP_{sa}}{dt} = \frac{1}{C_{sa}}\left(F_{o,l} - F_{sa}\right) \tag{A1.5}$$

Balance of Forces at Systemic Arteries

$$\frac{dF_{sa}}{dt} = \frac{1}{L_{sa}}\left(P_{sa} - P_{sp} - R_{sa} \times F_{sa}\right) \tag{A1.6}$$

Conservation of Mass at Peripheral Systemic Circulation

$$\frac{dP_{sp}}{dt} = \frac{1}{C_{hp} + C_{bp} + C_{mp} + C_{sp} + C_{ep}}\begin{pmatrix} F_{sa} - \frac{P_{sp} - P_{hv}}{R_{hp}} - \frac{P_{sp} - P_{bv}}{R_{bp}} - \frac{P_{sp} - P_{mv}}{R_{mp}} \\ -\frac{P_{sp} - P_{sv}}{R_{sp}} - \frac{P_{sp} - P_{ev}}{R_{ep}} \end{pmatrix} \tag{A1.7}$$

Conservation of Mass at Heart Veins

$$\frac{dP_{hv}}{dt} = \frac{1}{C_{hv}}\left(\frac{P_{sp} - P_{hv}}{R_{hp}} - \frac{P_{hv} - P_{ra}}{R_{hv}}\right) \tag{A1.8}$$

Conservation of Mass at Brain Veins

$$\frac{dP_{bv}}{dt} = \frac{1}{C_{bv}}\left(\frac{P_{sp} - P_{bv}}{R_{bp}} - \frac{P_{bv} - P_{ra}}{R_{bv}}\right) \tag{A1.9}$$

Conservation of Mass at Muscle Veins

$$\frac{dP_{mv}}{dt}=\frac{1}{C_{mv}}\left(\frac{P_{sp}-P_{mv}}{R_{mp}}-\frac{P_{mv}-P_{ra}}{R_{mv}}-\frac{dV_{u,mv}}{dt}\right) \tag{A1.10}$$

Conservation of Mass at Splanchnic Veins

$$\frac{dP_{sv}}{dt}=\frac{1}{C_{sv}}\left(\frac{P_{sp}-P_{sv}}{R_{sp}}-\frac{P_{sv}-P_{ra}}{R_{sv}}-\frac{dV_{u,sv}}{dt}\right) \tag{A1.11}$$

Conservation of Mass at Extrasplanchnic Veins

$$P_{ev}=\frac{1}{C_{ev}}\begin{bmatrix} V_{tot}-C_{sa}P_{sa}-\left(C_{hp}+C_{bp}+C_{mp}+C_{sp}+C_{ep}\right)P_{sp} \\ -C_{bv}P_{bv}-C_{hv}P_{hv}-C_{mv}P_{mv}-C_{sv}P_{sv} \\ -C_{ra}P_{ra}-V_{rv}-C_{pa}P_{pa}-C_{pp}P_{pp}-C_{pv}P_{pv} \\ -C_{la}P_{la}-V_{lv}-V_{u} \end{bmatrix} \tag{A1.12}$$

$$V_u=\begin{bmatrix} V_{u,sa}+V_{u,hp}+V_{u,bp}+V_{u,mp}+V_{u,sp}+V_{u,ep} \\ +V_{u,hv}+V_{u,bv}+V_{u,mv}+V_{u,sv}+V_{u,ev} \\ +V_{u,ra}+V_{u,pa}+V_{u,pp}+V_{u,pv}+V_{u,la} \end{bmatrix}$$

Conservation of Mass at Left Atrium

$$\frac{dP_{la}}{dt}=\frac{1}{C_{la}}\left(\frac{P_{pv}-P_{la}}{R_{pv}}-F_{i,l}\right) \tag{A1.13}$$

Blood flow entering left ventricle

$$F_{i,l}=\begin{cases} 0 & if \quad P_{la}\le P_{lv} \\ \dfrac{P_{la}-P_{lv}}{R_{la}} & if \quad P_{la}>P_{lv} \end{cases} \tag{A1.14}$$

Conservation of Mass at left Ventricle

$$\frac{dV_{lv}}{dt}=F_{i,l}-F_{o,l} \tag{A1.15}$$

Cardiac Output From Left Ventricle

$$F_{o,l}=\begin{cases} 0 & if \quad P_{\max,lv}\le P_{sa} \\ \dfrac{P_{\max,lv}-P_{sa}}{R_{lv}} & if \quad P_{\max,lv}>P_{sa} \end{cases} \tag{A1.16}$$

Viscous Resistance of Left Ventricle

$$R_{lv}=k_{R,lv}\times P_{\max,lv} \tag{A1.17}$$

Instantaneous Left Ventricle Pressure

$$P_{\max,lv}(t)=\varphi(t)\times E_{\max,lv}\times\left(V_{lv}-V_{u,lv}\right)+\left(1-\varphi(t)\right)\times P_{o,lv}\times\left(e^{k_{E,lv}\times V_{lv}}-1\right) \tag{A1.18}$$

$$\varphi(t)=\begin{cases}\sin^2\left[\dfrac{\pi\times T(t)}{T_{sys}(t)}\times u\right] & 0\le u\le \dfrac{T_{sys}}{T}\\ 0 & \dfrac{T_{sys}}{T}\le u\le 1\end{cases}$$

$$u(t)=frac(\xi)=abs\left(\xi-round(\xi)\right) \qquad \text{(A1.19)}$$

$$\frac{d\xi}{dt}=\frac{1}{T(t)}$$

$$T_{sys}=T_{sys,0}-k_{sys}\times\frac{1}{T}$$

Conservation of Mass at Right Atrium

$$\frac{dP_{ra}}{dt}=\frac{1}{C_{ra}}\left(\frac{P_{hv}-P_{ra}}{R_{hv}}+\frac{P_{bv}-P_{ra}}{R_{bv}}+\frac{P_{mv}-P_{ra}}{R_{mv}}+\frac{P_{sv}-P_{ra}}{R_{sv}}+\frac{P_{ev}-P_{ra}}{R_{ev}}-F_{i,r}\right) \qquad \text{(A1.20)}$$

Blood flow entering right ventricle

$$F_{i,r}=\begin{cases}0 & if \quad P_{ra}\le P_{rv}\\ \dfrac{P_{ra}-P_{rv}}{R_{ra}} & if \quad P_{ra}>P_{rv}\end{cases} \qquad \text{(A1.21)}$$

Conservation of Mass at Right Ventricle

$$\frac{dV_{rv}}{dt}=F_{i,r}-F_{o,r} \qquad \text{(A1.22)}$$

Cardiac Output From Right Ventricle

$$F_{o,r}=\begin{cases}0 & if \quad P_{\max,rv}\le P_{pa}\\ \dfrac{P_{\max,rv}-P_{pa}}{R_{rv}} & if \quad P_{\max,rv}>P_{pa}\end{cases} \qquad \text{(A1.23)}$$

Viscous Resistance of Right Ventricle

$$R_{rv}=k_{R,rv}\times P_{\max,rv} \qquad \text{(A1.24)}$$

Instantaneous Right Ventricle Pressure

$$P_{\max,rv}(t)=\varphi(t)\times E_{\max,rv}\times\left(V_{rv}-V_{u,rv}\right)+\left(1-\varphi(t)\right)\times P_{o,rv}\times\left(e^{k_{E,rv}\times V_{rv}}-1\right) \qquad \text{(A1.25)}$$

Baroreceptors

$$f_{ab}=\frac{f_{ab,\min}+f_{ab,\max}\times e^{\frac{\tilde{P}-P_n}{k_{ab}}}}{1+e^{\frac{\tilde{P}-P_n}{k_{ab}}}}$$

$$k_{ab}=\frac{f_{ab,\max}-f_{ab,\min}}{4\times G_b} \qquad \text{A1.26)}$$

$$\tau_{pb}\times\frac{d\tilde{P}}{dt}=P_{sa}+\tau_{zb}\times\frac{dP_{sa}}{dt}-\tilde{P}$$

Chemoreceptors

$$\frac{df_{ac}}{dt} = \frac{1}{\tau_c} \times \left(-f_{ac} + \varphi_{ac}\right)$$
$$\varphi_{ac} = \frac{f_{ac,\max} + f_{ac,\min} \times e^{\frac{P_{as_{O_2}} - P_{as_{O_2 n}}}{k_{ac}}}}{1 + e^{\frac{P_{as_{O_2}} - P_{as_{O_2 n}}}{k_{ac}}}} \qquad (0.0.27)$$

Pulmonary Receptors

$$\frac{df_{ap}}{dt} = \frac{1}{\tau_p} \times \left(-f_{ap} + \varphi_{ap}\right) \qquad (0.0.28)$$
$$\varphi_{ap} = G_{ap} \times V_T$$

Efferent Sympathetic Activity

$$f_{sp} = \begin{cases} f_{es,\infty} + (f_{es,0} - f_{es,\infty}) \times e^{k_{es} \times (-W_{b,sp} \times f_{ab} + W_{c,sp} \times f_{ac} - W_{p,sp} \times f_{ap} - \theta_{sp})} & if\ f_{sp} < f_{es,\max} \\ f_{es,\max} & if\ f_{sp} \geq f_{es,\max} \end{cases}$$
$$f_{sh} = \begin{cases} f_{es,\infty} + (f_{es,0} - f_{es,\infty}) \times e^{k_{es} \times (-W_{b,sh} \times f_{ab} + W_{c,sh} \times f_{ac} - \theta_{sh})} & if\ f_{sh} < f_{es,\max} \\ f_{es,\max} & if\ f_{sh} \geq f_{es,\max} \end{cases} \qquad (0.0.29)$$

Efferent Parassympathetic Activity

$$f_v = \frac{f_{ev,0} + f_{ev,\infty} \times e^{\frac{f_{ab} - f_{ab,0}}{k_{ev}}}}{1 + e^{\frac{f_{ab} - f_{ab,0}}{k_{ev}}}} + W_{c,v} \times f_{ac} - W_{p,v} \times f_{ap} - \theta_v \qquad (0.0.30)$$

Peripheral Resistance Dynamic

$$
\begin{aligned}
&R_{sp}(t) = \Delta R_{sp}(t) + R_{sp,0} \\
&\frac{d\Delta R_{sp}}{dt} = \frac{1}{\tau_{R_{sp}}} \times (-\Delta R_{sp} + \sigma_{R_{sp}}) \\
&\sigma_{R_{sp}} = \begin{cases} G_{R_{sp}} \times \ln[f_{sp}(t - D_{R_{sp}}) - f_{es,\min} + 1] & if\ f_{sp} \geq f_{es,\min} \\ 0 & if\ f_{sp} < f_{es,\min} \end{cases}
\end{aligned}
$$

$$
\begin{aligned}
&R_{mp}(t) = \Delta R_{mp}(t) + R_{mp,0} \\
&\frac{d\Delta R_{mp}}{dt} = \frac{1}{\tau_{R_{mp}}} \times (-\Delta R_{mp} + \sigma_{R_{mp}}) \\
&\sigma_{R_{mp}} = \begin{cases} G_{R_{mp}} \times \ln[f_{sp}(t - D_{R_{mp}}) - f_{es,\min} + 1] & if\ f_{sp} \geq f_{es,\min} \\ 0 & if\ f_{sp} < f_{es,\min} \end{cases}
\end{aligned}
$$

$$
\begin{aligned}
&R_{ep}(t) = \Delta R_{ep}(t) + R_{ep,0} \\
&\frac{d\Delta R_{ep}}{dt} = \frac{1}{\tau_{R_{ep}}} \times (-\Delta R_{ep} + \sigma_{R_{ep}}) \\
&\sigma_{R_{ep}} = \begin{cases} G_{R_{ep}} \times \ln[f_{sp}(t - D_{R_{ep}}) - f_{es,\min} + 1] & if\ f_{sp} \geq f_{es,\min} \\ 0 & if\ f_{sp} < f_{es,\min} \end{cases}
\end{aligned}
\tag{0.0.31}
$$

Elastance Dynamic

$$
\begin{aligned}
&E_{\max,rv}(t) = \Delta E_{\max,rv}(t) + E_{\max rv,0} \\
&\frac{d\Delta E_{\max,rv}}{dt} = \frac{1}{\tau_{E_{\max,rv}}} \times (-\Delta E_{\max,rv} + \sigma_{E_{\max,rv}}) \\
&\sigma_{E_{\max,rv}} = \begin{cases} G_{E_{\max,rv}} \times \ln[f_{sh}(t - D_{E_{\max,rv}}) - f_{es,\min} + 1] & if\ f_{sh} \geq f_{es,\min} \\ 0 & if\ f_{sh} < f_{es,\min} \end{cases} \\
&E_{\max,lv}(t) = \Delta E_{\max,lv}(t) + E_{\max,lv,0} \\
&\frac{d\Delta E_{\max,lv}}{dt} = \frac{1}{\tau_{E_{\max,rv}}} \times (-\Delta E_{\max,lv} + \sigma_{E_{\max,lv}}) \\
&\sigma_{E_{\max,lv}} = \begin{cases} G_{E_{\max,lv}} \times \ln[f_{sh}(t - D_{E_{\max,lv}}) - f_{es,\min} + 1] & if\ f_{sh} \geq f_{es,\min} \\ 0 & if\ f_{sh} < f_{es,\min} \end{cases}
\end{aligned}
\tag{0.0.32}
$$

Heart Rate Dynamic

$$
\begin{aligned}
&T(t) = \Delta T_S(t) + \Delta T_V(t) + T_0 \\
&\frac{d\Delta T_S}{dt} = \frac{1}{\tau_{T_S}} \times (-\Delta T_S + \sigma_{T_S}) \\
&\frac{d\Delta T_V}{dt} = \frac{1}{\tau_{T,V}} \times (-\Delta T_V + \sigma_{T,V}) \\
&\sigma_{T,S} = \begin{cases} G_{T,S} \times \ln[f_{sh}(t - D_{T_S}) - f_{es,\min} + 1] & if\ f_{sh} \geq f_{es,\min} \\ 0 & if\ f_{sh} < f_{es,\min} \end{cases} \\
&\sigma_{T_V} = G_{T,v} \times f_v(t - D_{T,V})
\end{aligned}
\tag{0.0.33}
$$

Unstressed Volume

$$
\begin{aligned}
&V_{u,mv}(t) = \Delta V_{u,mv}(t) + V_{u,mv,0} \\
&\frac{d\Delta V_{u,mv}}{dt} = \frac{1}{\tau_{V_{u,mv}}} \times (-\Delta V_{u,mv} + \sigma_{V_{u,mv}}) \\
&\sigma_{V_{u,mv}} = \begin{cases} G_{V_{u,mv}} \times \ln[f_{sp}(t - D_{V_{u,mv}}) - f_{es,\min} + 1] & if\ f_{sp} \geq f_{es,\min} \\ 0 & if\ f_{sp} < f_{es,\min} \end{cases} \\
\\
&V_{u,sv}(t) = \Delta V_{u,sv}(t) + V_{u,sv,0} \\
&\frac{d\Delta V_{u,sv}}{dt} = \frac{1}{\tau_{V_{u,sv}}} \times (-\Delta V_{u,sv} + \sigma_{V_{u,sv}}) \\
&\sigma_{V_{u,sv}} = \begin{cases} G_{V_{u,sv}} \times \ln[f_{sp}(t - D_{V_{u,sv}}) - f_{es,\min} + 1] & if\ f_{sp} \geq f_{es,\min} \\ 0 & if\ f_{sp} < f_{es,\min} \end{cases} \\
\\
&V_{u,ev}(t) = \Delta V_{u,ev}(t) + V_{u,ev,0} \\
&\frac{d\Delta V_{u,ev}}{dt} = \frac{1}{\tau_{V_{u,ev}}} \times (-\Delta V_{u,ev} + \sigma_{V_{u,ev}}) \\
&\sigma_{V_{u,ev}} = \begin{cases} G_{V_{u,ev}} \times \ln[f_{sp}(t - D_{V_{u,ev}}) - f_{es,\min} + 1] & if\ f_{sp} \geq f_{es,\min} \\ 0 & if\ f_{sp} < f_{es,\min} \end{cases}
\end{aligned}
\tag{0.0.34}
$$

Ventricle Pressure

$$P_{lv} = P_{\max,lv} - R_{lv} \times F_{o,l}$$
$$P_{rv} = P_{\max,rv} - R_{rv} \times F_{o,r} \quad (0.0.35)$$

Table 1. *Parameters characterizing the vascular system in the basal condition*

Compliance, ml/mmHg	Unstressed Volume, ml	Hydraulic Resistance, $mmHg \cdot s \cdot ml^{-1}$	Inertance, $mmHg \cdot s^2 \cdot ml^{-1}$
$C_{sa} = 0.28$	$V_{u,sa} = 0$	$R_{sa} = 0.06$	$L_{sa} = 0.22 \times 10^{-3}$
$C_{sp} = 2.05$	$V_{u,sp} = 274.4$	$R_{sp} = 3.307$	
$C_{ep} = 0.668$	$V_{u,ep} = 134.64$	$R_{ep} = 3.52$	
$C_{mp} = 0.525$	$V_{u,mp} = 105.8$	$R_{mp} = 4.48$	
$C_{bp} = 0.358$	$V_{u,bp} = 72.13$	$R_{bp} = 6.57$	
$C_{hp} = 0.119$	$V_{u,hp} = 24$	$R_{hp} = 19.71$	
$C_{sv} = 61.11$	$V_{u,sv} = 1{,}121$	$R_{sv} = 0.038$	
$C_{ev} = 20$	$V_{u,ev} = 550$	$R_{ev} = 0.04$	
$C_{mv} = 15.71$	$V_{u,mv} = 432.14$	$R_{mv} = 0.05$	
$C_{bv} = 10.71$	$V_{u,bv} = 294.64$	$R_{bv} = 0.075$	
$C_{hv} = 3.57$	$V_{u,hv} = 98.21$	$R_{hv} = 0.224$	
$C_{pa} = 0.76$	$V_{u,pa} = 0$	$R_{pa} = 0.023$	$L_{pa} = 0.18 \times 10^{-3}$
$C_{pp} = 5.80$	$V_{u,pp} = 123$	$R_{pp} = 0.0894$	
$C_{pv} = 25.37$	$V_{u,pv} = 120$	$R_{pv} = 0.0056$	

C, compliance; V_u, unstressed volume; *R*, hydraulic resistance; *L*, inertance; sa, systemic arterial; sp, splanchnic peripheral; ep, extrasplanchnic peripheral; mp, skeletal muscle peripheral; bp, brain peripheral; hp, coronary peripheral; sv, splanchnic venous; ev, extrasplanchnic venous; mv, skeletal muscle venous; bv, brain venous; hv, coronary venous; pa, pulmonary arterial; pp, pulmonary peripheral; pv, pulmonary venous. Total blood volume (V_{tot}) is 5,300 ml.

Table 2. *Basal values of parameters for reflex regulatory mechanisms*

Afferent baroreflex pathway (Eqs. 14–16)				
$\tau_{z,b} = 6.37\,s$		$f_{ab,min} = 2.52$ spikes/s		$P_n = 92$ mmHg
$\tau_{p,b} = 2.076\,s$		$f_{ab,max} = 47.78$ spikes/s		$k_{ab} = 11.76$ mmHg
Afferent chemoreflex pathway (Eqs. 17 and 18)				
$\tau_c = 2\,s$		$f_{ac,min} = 1.16$ spikes/s		$Po_{2n} = 45$ mmHg
		$f_{ac,max} = 17.07$ spikes/s		$k_{ac} = 29.27$ mmHg
Afferent pulmonary stretch receptors pathway (Eqs. 19 and 20)				
$\tau_p = 2\,s$				$G_{ap} = 23.29\ l^{-1} \cdot \text{spikes} \cdot s^{-1}$
Efferent sympathetic pathway (Eqs. 21 and 22)				
$f_{es,\infty} = 2.1$ spikes/s		$W_{b,sp} = 1$		$W_{b,sh} = 1$
$f_{es,0} = 16.11$ spikes/s		$W_{c,sp} = 5$		$W_{c,sh} = 1$
$f_{es,min} = 2.66$ spikes/s		$W_{p,sp} = 0.34$		
$f_{es,max} = 60$ spikes/s				
$k_{es} = 0.0675\,s$				
Efferent vagal pathway (Eq. 23)				
$f_{ev,\infty} = 6.3$ spikes/s				$W_{c,v} = 0.2$
$f_{ev,0} = 3.2$ spikes/s				$W_{p,v} = 0.103$
$f_{ab,0} = 25$ spikes/s				$\theta_v = -0.68$ spikes/s
$k_{ev} = 7.06$ spikes/s				
CNS hypoxic response (Eqs. 24–27)				
$\chi_{max,sp} = 13.32$ spikes/s	$\chi_{min,sp} = 7.33$ spikes/s		$Po_{2n,sp} = 30$ mmHg	$k_{isc,sp} = 2$ mmHg
$\chi_{max,sh} = 3.59$ spikes/s	$\chi_{min,sh} = -49.38$ spikes/s		$Po_{2n,sh} = 45$ mmHg	$k_{isc,sh} = 6$ mmHg
$\tau_{isc} = 30\,s$				
Ventilatory response (Eqs. 28 and 29)				
$G_v = 0.125\ l/\nu$	$\tau_v = 3\,s$	$D_v = 6\,s$	$V_{T_n} = 0.583$ liter	$f_{ac,n} = 3.6$ spikes/s
Reflex effectors (Eqs. 30–40)				
$G_{Emax,lv} = 0.475\ mmHg \cdot ml^{-1} \cdot \nu^{-1}$	$\tau_{Emax,lv} = 8\,s$	$D_{Emax,lv} = 2\,s$	$E_{max\,lv,0} = 2.392$ mmHg/ml	
$G_{Emax,rv} = 0.282\ mmHg \cdot ml^{-1} \cdot \nu^{-1}$	$\tau_{Emax,rv} = 8\,s$	$D_{Emax,rv} = 2\,s$	$E_{max\,rv,0} = 1.412$ mmHg/ml	
$G_{Rsp} = 0.695\ mmHg \cdot s \cdot ml^{-1} \cdot \nu^{-1}$	$\tau_{Rsp} = 6\,s$	$D_{Rsp} = 2\,s$	$R_{sp,0} = 2.49\ mmHg \cdot s \cdot ml^{-1}$	
$G_{Rep} = 1.94\ mmHg \cdot s \cdot ml^{-1} \cdot \nu^{-1}$	$\tau_{Rep} = 6\,s$	$D_{Rep} = 2\,s$	$R_{ep,0} = 1.655\ mmHg \cdot s \cdot ml^{-1}$	
$G_{Rmp} = 2.47\ mmHg \cdot s \cdot ml^{-1} \cdot \nu^{-1}$	$\tau_{Rmp} = 6\,s$	$D_{Rmp} = 2\,s$	$R_{mp,0} = 2.106\ mmHg \cdot s \cdot ml^{-1}$	
$G_{Vu,sv} = -265.4\ ml/\nu$	$\tau_{Vu,sv} = 20\,s$	$D_{Vu,sv} = 5\,s$	$V_{u,sv,0} = 1{,}435.4$ ml	
$G_{Vu,ev} = -74.21\ ml/\nu$	$\tau_{Vu,ev} = 20\,s$	$D_{Vu,ev} = 5\,s$	$V_{u,ev,0} = 640.73$ ml	
$G_{Vu,mv} = -58.29\ ml/\nu$	$\tau_{Vu,mv} = 20\,s$	$D_{Vu,mv} = 5\,s$	$V_{u,mv,0} = 503.26$ ml	
$G_{T,s} = -0.13\ s/\nu$	$\tau_{T,s} = 2\,s$	$D_{T,s} = 2\,s$	$T_0 = 0.58\,s$	
$G_{T,v} = 0.09\ s/\nu$	$\tau_{T,v} = 1.5\,s$	$D_{T,v} = 0.2\,s$		

CNS, central nervous system; $\dot{v}$, ventilation; see APPENDIX for explanation of other symbols. ν = spikes/s.

Table 2. *Parameters describing the right and left heart*

Left Heart	Right Heart
$C_{la} = 19.23$ ml/mmHg	$C_{ra} = 31.25$ ml/mmHg
$V_{u,la} = 25$ ml	$V_{u,ra} = 25$ ml
$R_{la} = 2.5 \cdot 10^{-3}$ mmHg·s·ml^{-1}	$R_{ra} = 2.5 \cdot 10^{-3}$ mmHg·s·ml^{-1}
$P_{0,lv} = 1.5$ mmHg	$P_{0,rv} = 1.5$ mmHg
$k_{E,lv} = 0.014$ ml^{-1}	$k_{E,rv} = 0.011$ ml^{-1}
$V_{u,lv} = 16.77$ ml	$V_{u,rv} = 40.8$
$E_{max,lv} = 2.95$ mmHg/ml	$E_{max,rv} = 1.75$ mmHg/ml
$k_{R,lv} = 3.75 \cdot 10^{-4}$ s/ml	$k_{R,rv} = 1.4 \cdot 10^{-3}$ s/ml

Basal heart period (T) is 0.833 s; k_{sys} and $T_{sys,0}$, which describe duration of systole as function of heart rate, are 0.075 s^2 and 0.5 s, respectively. R, resistance of atrioventricular valve; k_E and P_0, parameters describing end-diastolic pressure-volume function of ventricle; E_{max}, slope of end-systolic relationship; k_R, parameter describing dependence of ventricle resistance on isometric pressure. Subscripts: la, left atrium; ra, right atrium; lv, left ventricle; rv, right ventricle.