Quick-Start Guide to Cardiovascular Tuning

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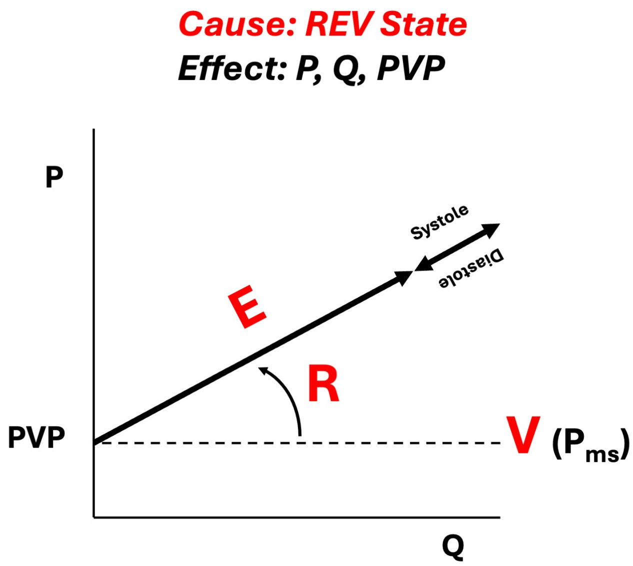
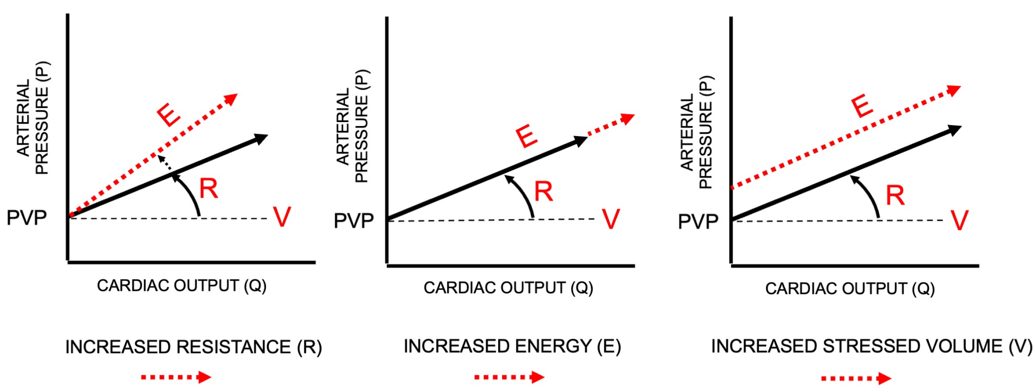
Follow the Energy. Mind the Tune.

1. Cardiovascular function is more than the sum of individual scalars, like blood pressure, heart rate, or cardiac output. Instead, the cardiovascular system functions as an integrated **energy distribution network**. The global energy state of that system is shaped by the combination of vascular resistance (R), cardiac-derived energy (E), and stressed blood volume (V). This **"REV" energy state** can be visualized as a vector, which may be plotted on a P-Q-PVP (pressure-flow-peripheral venous pressure) graph (Figure A and Reference 1). On that graph, R = slope of the vector, E = magnitude of the vector, and V = origin, or y-intercept, of the vector.[1] The y-intercept, or origin, is measured as PVP. Experimentally, PVP = P_{ms} (mean systemic pressure, or circulatory arrest pressure) = $(V-V_o)/C$, where V = total blood volume, V_o = unstressed volume, and C = venous compliance.[1,2,3,4,5] As a cardiovascular "fullness" measure, PVP requires no normalization to body mass.[1,3] The **REV vector** allows visualization of both the energy state *cause* (R, E, and V) and the hemodynamic *effect* (P, Q, PVP) of cardiovascular function on the same graph and embodied by the same vector.[1] In addition to allowing at-a-glance visualization and communication of overall cardiovascular function, the REV vector also provides a transparent history from the arrested state to steady-state function. It also offers a concise visual prediction of response to disease or therapy (Figure B).

A.



B.

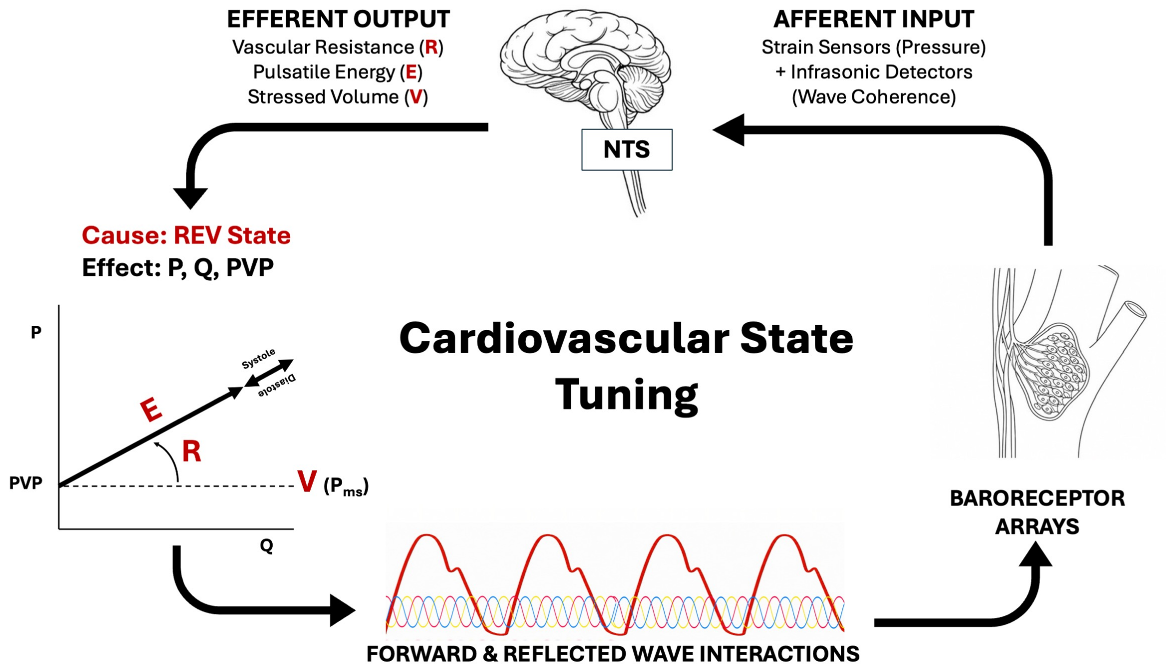


2. The cardiovascular system is also a **distributed resonance system**. The heart generates infrasonic low-frequency (< 20 Hz) pulse waves which reflect from impedance mismatches and other echogenic features in the peripheral vasculature.[6,7] Because these vascular features are shaped by Resistance (R), Energy (E), and Volume (V) (collectively, the REV state), the reflected infrasonic waves carry REV state information. The velocity of the pulse waves allows for several reflections within a single cardiacgenerated pulse, and these infrasonic waves materially shape the pulse-pressure waveform.[6] The reflected waves also impinge on carotid sinus and aortic arch baroreceptor arrays, which, in addition to acting as strain gauges that capture bulk flow pressure and volume excursions, also embed strain patterns from the reflected infrasonic waves.[6] The bulbous anatomy of the carotid sinus suggests that it can serve as an **acoustic lens**, or Helmholtz resonator. In addition, the **bilateral** arrangement of the carotid sinus baroreceptor arrays equips them to determine the **spatial and temporal coherence** of cardiovascular waveforms. Taken together, these features allow the baroreceptor arrays to act as **infrasonic "microphones"** in addition to performing as timing-sensitive strain gauges. Forward and reflected infrasonic waves also affect bulk flow of blood. When synchronized, or coherent, forward flow is augmented. When not synchronized, or incoherent, forward flow is impeded.[6,7]

3. Conventional explanations for cardiovascular control have focused on feedback management of a single scalar – blood pressure.[8] In addition to the fact that pressure is a result, not a cause, of cardiovascular function, such a limited control paradigm cannot account for steady-state function, functional adaptability (for example, to exercise), or initial cardiovascular system calibration. We propose a novel cardiovascular control regime (Figure C) that includes **dimensional compression** and **feedforward control** of the REV energy state itself, and thus, control of global cardiovascular function rather than control of a single scalar. We further propose a baroreceptor-mediated control regime that enforces harmonic coherence ("tuning") of the combined forward and backward-deflected infrasonic pulse waves that occur within each pulse. The coherence signal is the measure of synchronization, or tuning, of ventricular ejection, arterial resonance, and reflection timing in the baroreceptor-sensed pulse pressure waveform. In this control loop, the *nucleus tractus solitarius* (NTS) both *senses* and *enforces* reflected waveform coherence with the metronome features present in cardiac pulsatility. Stated in REV terms, the composite input pulse waveform encodes both dynamic **REV energy state information** as well as an embedded **coherence signal**. The autonomic output includes simultaneous control of the effects of vascular resistance (R) on energy dissipation; the effects of cardiac energy (E) on oscillatory energy storage and waveform energy projection; and the effects of stressed volume (V) on baseline compliance positioning and cardiac preload. This overall control regime provides a novel explanation for initial system calibration as well as for the remarkable efficiency and adaptability of cardiovascular function.

With increased understanding of biological complexity, new physiological properties emerge. At lower levels of organization, these governing rules are not merely inapparent - they are non-existent. In contrast, at higher levels of complexity, such as cardiovascular control, homeostatic features operate at a level of organization that cannot be predicted by anatomy alone. The three goals of steady-state function, developmental calibration, and adaptability require an **emergent control property**. The REV state tuning hypothesis leverages the known anatomy and physiology of the cardiovascular-baroreceptor system as well as the observed wave mechanics of cardiovascular infrasound to posit an emergent control property that can accomplish each of these tasks.

C.



4. It is intriguing to note that the anatomic and physiologic features of the cardiovascular-baroreceptor system, which together comprise a network of fluid-filled variable compliance conduits with distributed neural sensory arrays and brainstem-level integration, is capable of functioning as an "**antenna**" to receive external (not just internal) infrasound. If confirmed, "social" or intentional, infrasonic tuning may be possible.

5. Inaudible infrasound may be made audible, and with preserved harmonics, by applying a multiplicative function to low frequency (< 20 Hz) sounds. Such an "**octave multiplier**" device may have utility in bringing otherwise inaudible infrasound to the attention of, and evaluation by, our higher frequency auditory systems.

Selected References:

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Together, J.M and L.M. have Patents Pending related to the contents herein.