HEMODYNAMIC AND AUTONOMIC RESPONSE OF THE CARDIOVASCULAR SYSTEM TO TILT: GRAVITATIONAL DOSE-RESPONSE CURVES

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ABSTRACT

The cardiovascular system is strongly dependent on the gravitational environment. Gravitational changes cause mechanical fluid shifts and, in turn, autonomic effectors influence systemic circulation and cardiac control. Using a tilt paradigm, we investigated the acute hemodynamic response across a range of directions of the gravitational vector and to generate specific dose-response relationships of this gravitational dependency.

Twelve male subjects were tilted from 45° head up tilt (HUT) to 45° head down tilt (HDT) in 15° increments. This was repeated in supine and prone postures. We measured the steady-state acute hemodynamic response in a range of variables including heart rate (HR), stroke volume (SV), cardiac output (CO), oxygen consumption (VO2), total peripheral resistance (TPR), blood pressure (SBP and DBP), and autonomic indices derived from heart rate variability analysis. We further measured parameters related to cephalad blood flow including common carotid artery (CCA) cross-sectional area (CSA), internal jugular vein (IJV) CSA, and internal jugular vein pressure (IJVP).

Data show strong gravitational dependence in almost all variables considered, with the exception of oxygen consumption and CCA CSA, and with systolic blood pressure controlled to within approximately 3% across the tilt range. Hemodynamic responses are primarily driven by differential loading on the baroreflex receptors, combined with differences in venous return to the heart. HR, SV, CO, TPR, IJVP, and VO2 also exhibit significant difference between supine and prone response. HR, TPR, IJVP and VO2 were higher in the prone position (by 5.6±0.7 bpm, 0.07±0.03 mmHg.s/ml, 4.3±1.2 mmHg, and 0.04±0.01 l/min respectively), whilst SV and CO were higher in supine (8.8±1.6 ml and 0.19±0.10 l/min respectively). We hypothesize that thorax compression in the prone position leads to reduced venous return and increased sympathetic nervous activity, raising heart rate and systemic vascular resistance whilst lowering cardiac output and stroke volume [1]. CCA CSA remained constant with respect to tilt angle, position, and side, whilst IJV CSA was significantly different between the left and right sides. Linear models can be used to explain hemodynamic response for systemic cardiovascular parameters, whilst cephalad blood flow exhibits a highly non-linear response to tilt that can be explained using generalized additive models. Based on these data, we further generated gravitational dose-response curves that provide a comprehensive baseline from which to assess the efficacy of potential spaceflight countermeasures. Figure 1 shows examples of the dose-response curves for three of the measures taken. Results also assist clinical management of terrestrial surgery in prone posture or HDT positions.

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REFERENCES

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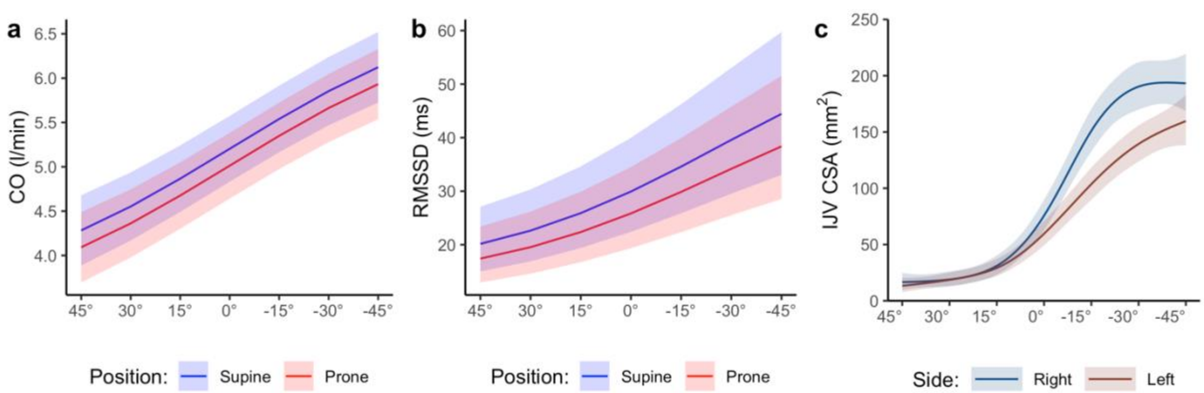

Figure 1: Gravitational dose-response curves constructed by tilting over the range 45° (head-up tilt) to –45° (head-down tilt) for a) cardiac output, b) root mean square of successive differences of NN-interval (a metric of parasympathetic activity), and c) internal jugular vein cross-sectional area.