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# Effects of body posture and exercise training on cardiorespiratory responses to exercise

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ABSTRACT

The primary aims of the present study were to evaluate cardiorespiratory responses to incremental head down tilt exercise and to determine if the cardiorespiratory adaptations obtained from endurance training in the head down tilt posture transfer to the upright posture. 22 men (25 ± 3 years) performed $\dot{V}O_2$peak cycle exercise tests in the upright and head down tilt postures. Of these, 11 men were endurance trained on a cycle ergometer in the upright posture for 8 weeks (upright training group; UTG) or in the upright posture for 4 weeks followed by 4 weeks in the head down tilt posture (head down training group; HTG). During acute exercise, $\dot{V}O_2$peak was decreased in the head down tilt posture compared to upright (2.01 ± 0.51 vs. 2.32 ± 0.61 l/min respectively, $P < 0.05$). Stroke volume (SV) at 100 W was greater during head down tilt cycling compared to the upright (77 ± 5 vs. 71 ± 4 ml/beat, $P < 0.05$). Following training $\dot{V}O_2$peak increased in both groups during upright exercise. However, $\dot{V}O_2$peak during head down tilt cycling was only increased in the HTG. Sub-maximal and peak SV in the HTG increased in both upright and head down tilt postures. SV in the UTG increased only in the upright posture and was unchanged during head down tilt cycling. In conclusion, acute head down tilt exercise increases sub-maximal SV compared to upright exercise. Furthermore, training in the head down tilt posture induces cardiorespiratory adaptations in both upright and head down tilt postures, while the adaptations to upright exercise training are primarily observed when upright exercise was performed.



## 1. Introduction

At rest, the transition from the upright to the supine posture increases ventricular preload and stroke volume (SV) (Bevegard et al., 1960, 1966; Poliner et al., 1980; Rushmer, 1959; Thadani and Parker, 1978). This altered gravitational vector and reduced hydrostatic column increase pulmonary capillary wedge pressure, an index of ventricular filling pressure, and ventricular end-diastolic volumes (Poliner et al., 1980; Thadani and Parker, 1978). Similar cardiovascular responses are observed during supine cycling. Poliner et al. (1980) demonstrated that supine cycling at an intermediate intensity (~98–122 W) increased left ventricular end-diastolic volume compared to upright cycling, suggesting greater cardiac filling. These findings are supported by additional reports of an elevated SV during supine exercise compared to upright (Bevegard et al., 1960, 1966; Egana et al., 2010; Leyk et al., 1992; Poliner et al., 1980; Ray and Cureton, 1991; Ray et al., 1990; Thadani and Parker, 1978).

Similar to the supine posture, the head down tilt posture has been widely used to further redistribute blood volume toward the central cavity (Gaffney et al., 1985; Kakurin et al., 1976a, 1976b; Nixon et al., 1979). Kakurin et al. (1976b) demonstrated that a head down tilt posture is associated with a greater central fluid shift compared to the supine position. As such, the head down tilt bed rest model is commonly used in place of the supine model to simulate the effects of microgravity. In addition, short duration head down tilt studies have consistently demonstrated a greater increase in central venous pressure and left ventricular end-diastolic volume compared to supine rest (Gaffney et al., 1985; Nixon et al., 1979). This increase in ventricular preload and chamber volume caused by the head down tilt posture, coupled with the Frank–Starling relationship, results in a greater SV compared to the supine posture (Rowell, 1993). However, to our knowledge no study has reported the effects of exercise on SV in the head down tilt posture.

In addition to postural differences in central cardiovascular responses, comparisons between dynamic upright and supine exercise models reveal that cycling in the supine position decreases both $\dot{V}O_2$peak and time-to-exhaustion relative to upright posture (DiMenna et al., 2010; Egana et al., 2006, 2007, 2010; Kato et al., 2011; Koga et al., 1999; Proctor et al., 1996; Ray and Cureton, 1991). Egana et al. (2006) demonstrated that the decrease in exercise

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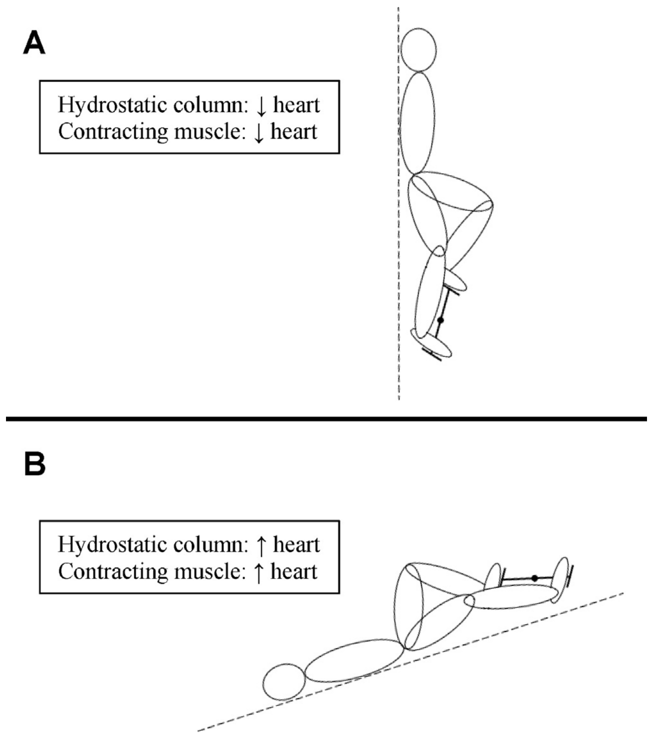


**Fig. 1.** A schematic representation of the hydrostatic column and contracting muscle mass relative to the heart during upright (A) and head down tilt (B) exercise. Notice the contrasting cardiovascular environment between the two postures.

time-to-fatigue between upright and supine exercise is correlated with the height of the hydrostatic column (Egana et al., 2006). Therefore, the decreased $\dot{V}O_2$peak previously observed during supine exercise is often attributed to a decreased gravitational assistance to muscle blood flow, which would be aggravated in head down tilt posture. However, to date, the forearm (Fitzpatrick et al., 1996; Hughson et al., 1996; Wright et al., 1999) and arm cranking (Koppo and Bouckaert, 2005) exercise models have been the primary methods used to examine the cardiorespiratory adjustments to exercise when the contracting muscle is placed above the heart. To our knowledge it remains unknown how dynamic large muscle mass exercise performance is affected when performed above heart-level, like that achieved with head down tilt posture (Fig. 1).

Training adaptations of the cardiorespiratory system in response to chronic exercise include increases in $\dot{V}O_2$peak, lactate threshold (LT), and SV (Jones and Carter, 2000). Previous studies have demonstrated a strong postural specificity for training induced cardiorespiratory adaptations. Ray and colleagues (Ray et al., 1990; Ray and Cureton, 1991) trained individuals for 8 weeks in either the upright or supine. Training consisted of a combination of high-intensity interval and endurance training. These investigators demonstrated significant increases in $VO_2$peak in both groups. However, the increase in $\dot{V}O_2$peak displayed significant postural specificity so that greater increases in aerobic capacity were seen when subjects were tested in the specific training posture. Similarly, each group only demonstrated a training induced increase in SV when measured in their respective training posture. These data suggest a lack of transfer between upright and supine postures. However, to date, it is unknown if the increased ventricular preload and chamber volumes associated with resting head down tilt posture compared to upright and supine postures will result in cardiorespiratory training adaptations that will transfer to traditional upright exercise.

The rational for the present study was that because effective ventricular filling is greater during resting head down tilt posture compared to supine and upright postures (Gaffney et al., 1985; Kakurin et al., 1976b; Nixon et al., 1979), cycling training in the head down tilt posture would result in greater ventricular adaptations compared to upright training and that the increased CO and SV would increase $\dot{V}O_2$peak when measured in both the upright and head down tilt postures. Therefore, the primary aims of the present study were to (1) compare the acute cardiorespiratory responses to incremental head down tilt exercise with those during upright exercise, and (2) determine if the cardiorespiratory adaptations obtained from endurance training in the head down tilt posture transfer to the upright condition. It was hypothesized that (i) head down tilt exercise would increase sub-maximal SV, but decrease $\dot{V}O_2$peak compared to upright exercise. Furthermore, it was hypothesized that (ii) endurance training in the upright posture would increase $\dot{V}O_2$peak, sub-maximal SV, and SVpeak during upright exercise, but not during head down tilt exercise, but that (iii) training in the head down title posture would increase $\dot{V}O_2$peak, sub-maximal SV, and SVpeak in both upright and head down tilt testing postures. In addition, it was hypothesized (iv) that the increase in sub-maximal and SVpeak would be greater after head down tilt training compared to upright.

## 2. Materials and methods

### 2.1. Subjects

22 men (age 25 ± 3 years (mean ± SD); stature 177.5 ± 8.2 cm; mass 75.0 ± 17.6 kg; BMI 23.8 ± 17.6 kg $m^{-2}$) completed the experiments. All subjects were free from known cardiovascular, pulmonary, or metabolic disease and were non-smokers as determined from medical history questionnaire. None were regularly participating in structured exercise activities before their involvement in the study. Verbal and written consent were obtained from all subjects following approval of the study by the Institutional Review Board for Research Involving Human Subjects at Kansas State University, which conformed to the Declaration of Helsenki.

### 2.2. Experimental design

All testing was completed in an air-conditioned laboratory at a temperature of 20–25 °C. Each subject performed two randomly ordered exercise protocols on different days. One testing session consisted of a graded cycling test in the upright posture, while in the other session a graded cycling test in the −6° head down tilt posture was performed (Fig. 1). Upright cycle tests were performed on a electronically braked cycle ergometer (800 Ergometer, SensorMedics, USA). Head down tilt cycle tests were performed on a mechanically braked Monarch 818E cycle ergometer mounted to a custom made apparatus that placed the subject in the appropriate exercising posture with the crank shaft ∼10 cm above the level of the subject's back resulting in −6° head down tilt posture. Both cycle ergometers were calibrated to ensure accurate work load settings prior to the beginning of the study and pilot work determined that each ergometer elicited similar exercise responses as evident by a similar $\dot{V}O_2$ (800 Ergometer, 1.11 ± 0.11 vs. Monarch, 1.16 ± 0.12 l/min, $P > 0.05$) and heart rate (800 Ergometer, 125 ± 20 vs. Monarch, 123 ± 16 bpm, $P > 0.05$) at 100 W. During head down tilt cycling subjects laid on a padded mat with their feet secured to the pedals. At each test the subject was positioned to allow a slight bend in the knee when the leg was fully extended and seat height was recorded to ensure consistency across testing sessions. Following 5-min of baseline rest, the subjects began cycling at 60 rpm at 20 W for additional 5-min. The work rate then progressively increased 25 W every minute until the subject could