Influence of Posture on Cardiac Output and Minute Ventilation During Exercise


In resting man, the cardiac output is higher in the horizontal position than in the upright position. It is, however, unknown whether this difference persists during the performance of exercise. This study was conducted to determine the influence of posture on the cardiac output in normal man during the performance of steady exercise with the legs. Concurrently, observations were also made of minute ventilation and oxygen uptake.

Methods

The subjects were four healthy medical students, three male and one female, whose ages ranged from 21 to 24 years. Exercise was performed at fixed loads of either 300 or 500 Kg.-M./min., using a bicycle ergometer* in which the work load could be preset, and was independent of the speed of pedaling. Cycle rate was maintained between 70 and 75 per minute. Observations were made in the supine and sitting postures, alternately. A strict time sequence was observed as follows: five minutes' rest; eight minutes' exercise with measurement of cardiac output between the fifth and sixth minutes, and expired air collection between the sixth and eighth minutes; posture changed; five minutes' rest. Observations were then repeated in the new posture in an identical fashion. In addition to 20 comparisons made during exercise, 8 were made at rest: each of the latter determinations was preceded by a rest period of 10 minutes.

Expired gas was collected over approximately two minutes, analyzed for oxygen,* and measured in a dry gas meter. Ventilatory volumes were expressed at ambient pressure, 37 C., saturated. Oxygen uptake was expressed at standard temperature and pressure, dry. Carbon dioxide content of expired gas was not measured, and inspired gas volume was assumed to be equal to expired.

Cardiac output was measured by an indicator-dilution method using Coomassie blue dye† and an ear oximeter technique described in full elsewhere.1, 2 The dye was injected into a superficial arm vein and flushed in with 7 ml. normal saline. Heart rate was obtained from a continuous electrocardiographic record.

Results

The mean values in each posture and the average difference of paired observations between the recumbent and sitting postures in the four subjects are shown in the table. Paired observations of circulatory and ventilatory data are plotted in figures 1 and 2. The oxygen uptake for equal work loads did not differ significantly in the two postures. During exercise, the average cardiac index and stroke index were approximately 12 per cent and 19 per cent lower in the sitting posture, while heart rate was approximately 6.7 per cent higher. These differences were significant at the 1 per cent level (Student's t-test). The few observations made at rest showed less marked differences between the two postures; these differences were not statistically significant. When related to oxygen uptake

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*Beekman, F3 Oxygen Analyzer.
†Kindly supplied by Messrs. Ayrart, McKenna, and Harrison, Montreal, Canada.
Table 1
Comparison of Data in Two Postures at Rest and During Exercise (Mean Values)

<table>
<thead>
<tr>
<th></th>
<th>Ventilatory data</th>
<th>Circulatory data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resp. rate</td>
<td><em>V</em></td>
</tr>
<tr>
<td></td>
<td>per min.</td>
<td>L/min.</td>
</tr>
<tr>
<td>REST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recumbent</td>
<td>8.0</td>
<td>8.00</td>
</tr>
<tr>
<td>Mean Δ (sit.—recum.)</td>
<td>+2.7*</td>
<td>+1.27†</td>
</tr>
<tr>
<td>S.D. difference</td>
<td>1.2</td>
<td>1.41</td>
</tr>
<tr>
<td>EXERCISE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recumbent 300 Kg./min.</td>
<td>11.8</td>
<td>25.07</td>
</tr>
<tr>
<td>Recumbent 300 Kg./min.</td>
<td>14.8</td>
<td>35.23</td>
</tr>
<tr>
<td>Mean Δ (sit.—recum.)</td>
<td>+3.21†</td>
<td>+6.29†</td>
</tr>
<tr>
<td>S.D. difference</td>
<td>2.2</td>
<td>6.12</td>
</tr>
</tbody>
</table>

*P < 0.01.  
†P < 0.005.  
‡P < 0.001.

consumption, the postural difference was still apparent. The ventilatory volume in the sitting posture, both during rest and exercise, was higher than in the recumbent posture—the result of increased respiratory frequency, tidal volume remaining unchanged.

Discussion

Many workers have reported that in resting man the cardiac output in the recumbent posture is higher than in the sitting or standing positions. Reduction of cardiac output has likewise been demonstrated on the tiltable as the subject is moved from the horizontal toward the vertical position. As these changes have generally been considered the result of venous pooling in the legs, it seemed possible that leg exercise might, by increasing venous return, reduce or abolish the postural difference observed in cardiac output at rest. In our studies this did not take place, and the reduction of output in the sitting posture was at least as great, and probably greater, during leg exercise than at rest.

It is of interest that, contrary to expectation, the maintenance of the sitting posture at rest does not appear to have caused a significant increase in oxygen uptake. Likewise, the relationship of oxygen consumption to external mechanical work was identical in the two postures.

It is not generally recognized that ventilation is greater in the sitting posture than in the recumbent. The mechanism of the difference is not obvious. There is evidence from the studies of Riley et al. that the upright posture is not associated with either hypoxia or hypercapnea. Thus, it is unlikely that the increase of ventilation when upright can be due to a reduction of diffusing capacity or to the disturbance of ventilation perfusion relationships known to occur in the upright posture. It may be, however, that the increase of ventilation is in some way related to the fall of cardiac output in the upright posture. The suggestion by Dutton et al. that the respiratory center may be influenced by the carbon dioxide tension of venous blood is perhaps relevant. Thus, a reduction in the cardiac output in the upright posture without change in the oxygen consumption would result in an elevation of venous pCO₂ and, if Dutton's hypothesis proves to be correct, this might serve as a respiratory stimulus.
POSTURE AND CARDIAC OUTPUT

Comparison of circulatory data in sitting and recumbent postures. Measurement of oxygen consumption not available in two exercise experiments affecting three comparisons. 

Figure 1

Whatever the mechanism of these changes, however, it is important, when considering circulatory or respiratory data recorded in different body positions, to bear in mind the smaller cardiac output and stroke volume and higher ventilatory volume which is associated with the upright posture by comparison with the supine, even during steady-state exercise.

Summary

In four normal subjects, cardiac output, oxygen uptake, and ventilatory volume were compared on 8 occasions at rest and on 20 occasions during exercise in the recumbent and sitting postures. The oxygen uptake was not significantly different in the two postures either at rest or at equal external work loads. In the sitting posture during exercise, the cardiac index was approximately 12 per cent and stroke index 19 per cent lower than in the supine posture. Ventilation was significantly higher because of an increase in respiratory frequency.

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MAURICE MCGREGOR, WILLIAM ADAM and PAUL SEKELJ

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