Age Changes in Heart Rate and Blood Pressure Responses to Tilting and Standardized Exercise

By Arthur H. Norris, B.A., Nathan W. Shock, Ph.D., and Marvin J. Yiengst, B.S.

Tilting and standardized exercise caused extensive shifts of heart rate and auscultatory blood pressures in 140 ambulatory male subjects from 20 to 92 years of age. Following similar exercise, the older subjects showed a greater increase of heart rate and pulse pressure than did the younger subjects who compensated the changes caused by tilting more completely and rapidly than did the older subjects. These slower compensatory responses of older subjects should be considered in the interpretation of metabolic recovery rates after exercise.

TILTING and step-test exercise have been used often as cardiovascular stress situations and included in tests of the ability of the human subject to make proper hemodynamic adjustments.\(^1\)\(^-\)\(^4\)

Certain questions have arisen in connection with the interpretation of (1) the results of treadmill or other exercise experiments in which the subject undergoes a change in posture between the exercise and the recovery period, and (2) age data gathered from experiments where old and young subjects were stimulated by different levels of stress.

A change in posture would seem to introduce a large cardiovascular component into the recovery pattern of cardiovascular and metabolism measurements following stress situations, although, such change might not interfere with the estimation of an over-all metabolic effect.

Everyday tasks confronting older people are essentially the same as those confronting young people except where special allowance is made for age. Individual differences make it difficult to equalize stress for subjects of various ages by relating the stress to age, weight, height, surface area, or other individual characteristics.

In order to understand better the effects of posture and age, experiments were performed to answer the following questions:

1. What changes in heart rate and blood pressure occur after tilting human subjects (feet down) to 45 degrees and to the standing position? Are there age differences in these changes?

2. What age differences occur in heart rate and blood pressure responses to exercise which is standardized for all subjects with respect both to rate and to total amount?

METHODS

Subjects. The subjects tested were 140 ambulatory male patients, employees, and staff members of the Baltimore City Hospitals between 20 and 92 years of age. The only requirement was the ability to perform the exercise.

Design. Each subject was tested once according to the following schedule: At zero time subjects reclined on the tilt table in the horizontal position. A standard blood pressure cuff and a stethoscope pickup were then fitted to the right arm. The heart sounds were recorded continuously from a transducer with low-frequency response. Measurements of systolic and diastolic blood pressure were started at nine minutes after zero time and read on the same schedule for all subjects.

Subjects were tilted feet down to 45 degrees at 15 minutes, returned to horizontal at 25 minutes, tilted to standing at 35 minutes, and sat in a straight chair at 41 minutes. They stood at 47 minutes and exercised until 48.5 minutes, when they again sat in the chair until 56.5 minutes. The exercise was performed by walking over two 9 inch steps (total height, 18 inches) the number of times required by each subject to perform 222 kilogram-meters (S.D. dist. = 16 Kg.M.) of work in the 1.5 minutes al-
lowed. Support to the subject was provided by a foot-board and the table in all positions of tilt.

Blood pressures were read at 30-second intervals for four minutes after tilt and exercise. The first reading was taken 15 seconds after change in position. Heart rates were counted from the record over 15-second intervals and were measured for each 15-second interval for two minutes after tilts and for three minutes after exercise.

_Treatment of the data._ Mean values by age decades were computed for each measurement (systolic blood pressure, diastolic blood pressure and heart rate) at each time interval and plotted against time. An analysis of variance was used to assess the statistical significance of differences observed in the average curves. For the analysis, the total variance was partitioned as shown in table 2.

**RESULTS**

Figure 1 shows for three of the age groups (20–29 years, 60–69 years, 80–92 years) the average values of systolic blood pressure, diastolic blood pressure, and heart rate plotted against time after the beginning of the experiment.

Although the instantaneous values for heart rate and blood pressure upon tilting or at the end of exercise cannot be determined with the methods used here, the direction of these shifts can be estimated from the slope of the curve following the readings taken 15 seconds after change in position or after exercise (fig. 1). Table 1 shows the direction of these shifts.
systolic blood pressure levels than did the young, while diastolic blood pressure levels remained unchanged. Also, after this tilt, the heart rate increased more in the young subjects than in the old.

Following tilt to the standing position the systolic blood pressure decreased similarly* in both old and young subjects, while the diastolic blood pressure levels show a greater drop and slower recovery in the old subjects than in the young. Also, after tilt to standing, the heart rate increased more in the young subjects than in the old.

**Table 1.—Direction of Blood Pressure and Heart Rate Responses to Change in Position**

<table>
<thead>
<tr>
<th>Position Change</th>
<th>Systolic B.P.</th>
<th>Diastolic B.P.</th>
<th>Heart Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>From horizontal to 45° tilt</td>
<td>decrease</td>
<td>no change</td>
<td>increase</td>
</tr>
<tr>
<td>From horizontal to standing</td>
<td>decrease</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>From 45° tilt to horizontal</td>
<td>increase</td>
<td>decrease</td>
<td>decrease</td>
</tr>
<tr>
<td>From standing to sitting</td>
<td>increase</td>
<td>no change</td>
<td>decrease</td>
</tr>
<tr>
<td>From standing exercise to sitting</td>
<td>increase</td>
<td>no change</td>
<td>increase</td>
</tr>
</tbody>
</table>

Comparison of observations taken with the subject, *sitting after standing*, and *sitting after exercise in the standing position*, shows that:

1. Older subjects increased their systolic blood pressure levels more after exercise, and returned to pre-exercise levels later than did the young.

2. There were no age differences in diastolic blood pressure responses after exercise.

3. After exercise the heart rate increased more and reached postexercise levels later in the old than in the young subjects.

For a quantitative verification of the above conclusions, an analysis of variance was applied to the first nine blood pressure readings and the first 11 heart rate estimates made after tilt to 45 degrees, tilt to standing, sitting after standing, and sitting after exercise in the standing position. The two tilts were compared as were the two conditions of sitting. The results of these analyses are summarized in table 2. Variance ratios were taken as indicating significant primary effects or interaction effects when $p < 0.05$. Asterisks indicate ratios significant with $p < 0.001$.

These analyses indicate that after tilting and exercise there is a significant age difference in levels of systolic blood pressure (age effect, systolic blood pressure),* but no significant age difference in diastolic blood pressure or heart rate levels (age effect, diastolic blood pressure, heart rate). Further, individuals can be distinguished by all measures (individuals—within age—effect). For all measures there is a significant effect due to the difference between the 45 degree tilt and the tilt to standing (position effect). There is, also, a significant effect for all measures due to the difference between sitting after standing and sitting after exercise in the standing position (exercise effect). Moreover, there is a significant time trend in all measures both with (*position X time effect*) and without (*time effect*) respect to differences in position and levels of exercise.

The previous statements concerning the changes after 45 degree tilt, tilt to standing, and exercise are confirmed by the analysis of variance. Differences with age in rates of change are referred to *age X time interaction effects*, while differences with age in levels are referred to *age X position interaction effects*.

In addition, the sharp systolic blood pressure changes in the 60 year and the 70 year age groups following tilt to standing (tilt position 2) are reflected in a significant *age X time interaction effect* within position 2 ($f = 2.62$). The age differences in the time curves for heart rate following the 45 degree tilt are reflected by a significant *age X time interaction effect* taken over both positions ($f = 1.75$).

* Reference is made to table 2, analysis of variance. The statement is referred to age effect and systolic blood pressure both for tilt and for exercise. The F ratios are significant.
Table 2.—Summary of Variance Ratios (F Ratios) for Blood Pressure and Heart Rate Data Following Tilt to 45 degrees and 90 Degrees and Following Sitting after Standing and Sitting after Exercise

<table>
<thead>
<tr>
<th>Effect</th>
<th>Code</th>
<th>Error Mean Square</th>
<th>Blood Pressure</th>
<th>Heart Rate</th>
<th>D.F.</th>
<th>Blood Pressure</th>
<th>Heart Rate</th>
<th>D.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>A</td>
<td>B</td>
<td>4.90S*</td>
<td>1.96NS</td>
<td>5-133</td>
<td>1.40NS</td>
<td>5-133</td>
<td></td>
</tr>
<tr>
<td>Individual (within age)</td>
<td>B</td>
<td>H+I+J</td>
<td>176.64S*</td>
<td>227.18S*</td>
<td>134-2278</td>
<td>196.10S*</td>
<td>133-2793</td>
<td>151.76S*</td>
</tr>
<tr>
<td>Position</td>
<td>C</td>
<td>H</td>
<td>43.04S*</td>
<td>167.47S*</td>
<td>1-133</td>
<td>85.24S*</td>
<td>1-133</td>
<td>182.28S*</td>
</tr>
<tr>
<td>Time</td>
<td>D</td>
<td>I</td>
<td>36.94S*</td>
<td>7.32S*</td>
<td>8-1072</td>
<td>2.33S*</td>
<td>10-1330</td>
<td>66.38S*</td>
</tr>
<tr>
<td>Age × Position</td>
<td>E</td>
<td>H</td>
<td>5.05S*</td>
<td>1.25NS</td>
<td>5-134</td>
<td>5.37S*</td>
<td>5-133</td>
<td>7.20S*</td>
</tr>
<tr>
<td>Age × Time</td>
<td>F</td>
<td>I</td>
<td>3.45S*</td>
<td>2.80S*</td>
<td>40-1072</td>
<td>1.75S*</td>
<td>50-1330</td>
<td>1.29NS</td>
</tr>
<tr>
<td>Position × Time</td>
<td>G</td>
<td>J</td>
<td>5.99S*</td>
<td>95.57S*</td>
<td>8-1072</td>
<td>11.42S*</td>
<td>10-1330</td>
<td>7.43S*</td>
</tr>
<tr>
<td>Age × Time × Position</td>
<td>K</td>
<td></td>
<td>0.77NS</td>
<td>28.50S*</td>
<td>40-600</td>
<td>1.26NS</td>
<td>50-640</td>
<td>1.00NS</td>
</tr>
<tr>
<td>Age × Time (Position 1)</td>
<td>L</td>
<td>I</td>
<td>1.73S</td>
<td>1.01NS</td>
<td>40-1072</td>
<td>1.60NS</td>
<td>50-1330</td>
<td>0.52NS</td>
</tr>
<tr>
<td>Age × Time (Position 2)</td>
<td>M</td>
<td>I</td>
<td>2.62S*</td>
<td>21.60S*</td>
<td>40-1072</td>
<td>0.67NS</td>
<td>50-1330</td>
<td>1.76S*</td>
</tr>
<tr>
<td>Individuals × position (within age)</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individuals × time (within age)</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individuals × time × position (within age)</td>
<td>J</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = Significant (p < 0.05)
S* = Significant (p < 0.001)
NS = Not significant (p > 0.05)
* Degrees of Freedom.

b Mean square based on variation of initial resting horizontal pre-tilt estimates of appropriate response.

* “Position” should read “Exercise” for the second part [Exercise (Before and After)] of this table. Position 1 = before exercise. Position 2 = after exercise.
This latter difference may be attributed to the 45 degree tilt because the age \times time interaction within tilt position 1 \((f = 1.60)\) may be significant \((p = <0.10)\) while the age \times time interaction within tilt position 2 \((f = 0.67)\) is not significant.

To test the conclusion that there was a greater systolic blood pressure drop in older subjects than in young subjects following tilt to 45 degrees, the regression on age of the differences between the systolic blood pressure reading before the 45 degree tilt and the systolic blood pressure reading after the 45 degree tilt was estimated. A \(t\) test indicated that the regression was significant \((t_{128} = 19.19)\).

**Discussion**

The instantaneous alterations in blood pressure following change in position (table 1) are compatible with hydrostatic concepts. The heart rate responds very rapidly to compensate these pressure shifts. Statements concerning age differences in volume distribution of blood cannot be made, since they have not been quantitated.

The progressive adjustments of systolic blood pressure following change in position were more or less uniform for all age groups except after the 45 degree tilt where the older subjects showed a larger drop in systolic pressure than did the young. This less adequate response of the older subjects to the small postural shift, may be due to a less sensitive vasomotor response or to a differential aortic distensibility between old and young. On the other hand, the vertical tilt represents a stimulus which effects equal response of systolic pressure in all age groups. This may be the result of the larger, now equally effective stimulus or a differential response between old and young, with structural limitation to the blood shift in the older subject.

Changes in diastolic pressure may be considered to reflect changes in arterial resistance if pulse pressure and heart rate do not change in the same direction. For example, curves of recovery from exercise suggest that despite increased heart rate and systolic pressure during exercise, diastolic pressure was decreased reflecting the vasodilation of exercise. Similarly, the changes in diastolic pressure were opposite to the changes in pulse pressure following tilt to 45 degrees and return to horizontal position. Here the 20 year old group showed the greatest and most rapid change. Following the tilt to standing, diastolic pressure was not maintained as well in the older subjects, although they showed no greater systolic fall than the younger subjects did. These relations suggest that the vasomotor changes normally induced by the postural maneuvers described, were less marked, and less prompt in our older subjects.

Heart rate responses were also more extensive in the younger subjects, although here there seems to be a gradation of response with age instead of a single outstanding age group difference, as in the diastolic blood pressure curves. Heart rates increased sharply in the face of decreased venous return to the heart and decreased sharply with increase in supply (return to horizontal or sitting positions).

Thus, on tilting, the older subjects show slower compensatory responses than do the young.

Systolic blood pressure and heart rate responses to exercise increased with increasing age, while diastolic blood pressure response seemed to be similar for various ages. There was, then, during and after exercise an increase in pulse pressure and heart rate which was greater in the older subjects. These differences might be the result of differences in cardiac output, were it not for the fact that decreased aortic distensibility with age could explain the increased pulse pressure response.

Even without postulating a difference in cardiac output, the fact that the older subjects recover from these greater increases of systolic blood pressure and heart rate more slowly than did the young, plus the fact that the older subjects compensated the changes caused by tilting more slowly than did the young, suggest that there is a component of hemodynamic equilibration at the vasomotor level which may contribute to the slowing of metabolic recovery in older people following exercise. Although the magnitude of this component might be expected to be small, it should
be considered as a possible source of variability in the interpretation of exercise recovery curves.

Summary

Heart rates and brachial auscultatory blood pressures were measured in 140 ambulatory male subjects between 20 and 92 years of age following tilt to 45 degrees, tilt to standing, and step exercise of 222 Kilogram-meters of work in 1.5 minutes.

The data presented indicate that there are age differences in heart rate and blood pressure responses to and recovery from the stimuli employed.

Following tilt to 45 degrees, older subjects showed greater decrease and slower recovery of systolic blood pressure, and smaller increase in heart rate than did the young, while diastolic blood pressure levels remained unchanged in all groups.

Following tilt to standing, older subjects showed a greater decrease and slower recovery of diastolic blood pressure, and smaller increase in heart rate than did the young, while systolic blood pressures decreased similarly in both old and young.

Following exercise of 222 Kilogram-meters (S.D. = 16 Kg.M.) in 1.5 minutes older subjects showed slower recovery from greater increase of systolic blood pressure and heart rate than did the young, while diastolic blood pressures showed similar time curves for different age groups.

The data presented suggest that changes in posture and changes in age should be reflected in cardiovascular and metabolic recovery curves following exercise.

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Sumario Español

Inclinaciones y ejercicios normalizados causaron extensos cambios en el pulso y la presión arterial auscultatoria en 140 sujetos hombres ambulatorios entre las edades de 20 a 92 años. Luego de ejercicio similar, los sujetos mayores mostraron un incremento mayor en el número de contracciones cardiacas y en la presión de pulso que el grupo joven, quien compensó los cambios producidos por inclinación más completamente y rápidamente que el grupo mayor. Las respuestas compensatorias de los sujetos mayores se deben considerar en la interpretación del promedio de recobro metabólico luego del ejercicio.

References

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