The measurement of cardiovascular and respiratory functions is important for the evaluation of physical fitness related to the changes in the heart rate and blood pressure caused by the exercise loads and postures.

This study was started after the author and his co-workers had carried out simple cardiovascular tests after squatting exercises and produced some standards of evaluation for screening test. However, the squatting exercises were too light for well-trained athletes. The author thus began a study based on the forty milimeter mercury test as another method that could give different loads to the athletes.

Fifty-six Japanese athletes, 46 males and 10 females, participated in the test. Electrocardiogram and electro-tachogram were recorded at the same time. Moreover, the Harvard Step Test was given to 26 subjects and simple breath-holding tests, without mercury manometer, were performed.

There are some conclusions that can be made from this study.

(1) Those who held long breath-holding duration showed the periodical variation of the heart rate, from 10 to 20 seconds, during breath-holding.
(2) In the group with longer breath-holding duration, the average heart rate during breath-holding was low.
(3) The correlation was found high between breath-holding using mercury manometer. And the correlation was also found high between the average heart rate during breath-holding and Harvard Step Test score.
(4) It is concluded that heart rate during breath-holding and breath-holding duration in the mercury test will be useful as an evaluation factor for athletes.

Introduction

The measurement of cardiovascular and respiratory functions is important for evaluation of physical fitness related to the changes in heart rate and blood pressure caused by the exercise loads and postures. It is also useful for evaluation of the present conditions of physical fitness.

The present study was started after the author and his co-workers had carried out simple cardiovascular tests after squatting exercises, and produced some standards of evaluation for screening test(11). However, the squatting exercises were too light for well trained athletes, the author thus began a study based on the forty millimeter mercury test as another method that could give different loads to the athletes.

Procedure

Fifty-six Japanese athletes, 46 males and 10 females, participated in the test. They were well-trained athletes and the candidates for the Olympic Games. The subjects were first requested to sit on a chair, and blow into a mercury manometes with enough pressure to keep the mercury column at a height of 40 mm., and then to try to keep it there as long as possible. Electrocardiogram, using the II limb lead, and cardio-tachogram were recorded at the same time. The recording was begun 20 seconds before breath-holding, and finished about 90 seconds after breath-holding. Moreover, the Harvard Step Test was given to 26 of the 56 subjects and simple breath-holding tests, without mercury manometer, were performed.

Results

Since it was the purpose of this study to evaluate the individual athletes, it was necessary to record the heart rate responses. In Figure 1 the heart beat interval is shown on the vertical axis, while the time duration is on the horizontal axis. At the same time, the heart rate was measured every five seconds according to Flack's method(12)(13)(14) on the vertical axis, and the time duration on the horizontal on another graph. In the graph for heart beat intervals with a frequency between 4 and 5 seconds caused by breathing is cancelled out, and do not appear on the diagram, but greater changes with a frequency bet-
Yusa: Breath-Holding Test as a Measure of Cardiovascular Fitness

Figure 1. Cardio-tachogram of a subject shown by Flack's method.

Figure 2. Heart rate responses in five-seconds periods before, during and after breath-holding on fifty-six athletes.

Figure 3. Breath-holding duration of subjects participating in various athletic activities.

Figure 4. Time duration of breath-holding and heart rate responses of three groups.

ween 10 and 20 seconds are shown. The levels are higher in tachycardia and they are lower in bradycardia, contrary to ordinary cardio-tachograms. The gray portion of this graph indicates the changes during breath-holding.

Figure 2 illustrates the heart rate responses before, during and after 40mm Hg breath-holding on 56 subjects, in order of breath-holding durations. The black portions indicate the changes during breath-holding. Figure 3 shows the changes classified according to athletic activities. The maximum for males was 86 seconds, the minimum, 17 seconds, and the average, 43.4 seconds. For females, the maximum was 35 seconds, the minimum, 17 seconds, and the average, 25 seconds. Figure 4 shows the subjects divided into three groups by breath-holding duration. These three groups consist of (1) those who hold for 51 seconds or above, (2) from 31 to 50 seconds, and (3) 30 seconds or below. In the group with longer duration,
the average heart rate was lower, and greater changes were observed in heart rate during breath-holding.

When the electrocardiograms were investigated, it was found that some subjects showed depression of the T-wave at the beginning of breath-holding, while others showed temporary declines in the height of QRS complex. Still some others showed extrasystole at the time breath-holding was stopped. However, most subjects showed gradual depression of the T-wave when breath-holding was over. Extrasystole was observed in 9 of the 56 subjects, and Table 1 shows the subjects who showed extrasystole. Only one subject showed extrasystole at the beginning of breath-holding, but eight others showed it immediately after breath-holding.

Table 1. Breath-Holding Duration and Time Extrasystole Appears

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sport</th>
<th>Breath-holding duration</th>
<th>Time of appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Soccer</td>
<td>69.5 sec.</td>
<td>1 sec. and 11 sec. after test</td>
</tr>
<tr>
<td>B</td>
<td>Soccer</td>
<td>65.0</td>
<td>2 sec. after test</td>
</tr>
<tr>
<td>C</td>
<td>Hockey</td>
<td>61.0</td>
<td>Immediately after test</td>
</tr>
<tr>
<td>D</td>
<td>Rowing</td>
<td>44.0</td>
<td>Immediately after test</td>
</tr>
<tr>
<td>E</td>
<td>Judo</td>
<td>39.5</td>
<td>1 sec. after test</td>
</tr>
<tr>
<td>F</td>
<td>Wrestling</td>
<td>38.0</td>
<td>2 sec. after test</td>
</tr>
<tr>
<td>G*</td>
<td>Track</td>
<td>34.0</td>
<td>Immediately after test</td>
</tr>
<tr>
<td>H*</td>
<td>Track</td>
<td>20.0</td>
<td>2 sec. after test</td>
</tr>
<tr>
<td>I</td>
<td>Boxing</td>
<td>52.0</td>
<td>Beginning of test</td>
</tr>
</tbody>
</table>

* Female

Table 2. Correlation Coefficients Between Breath-Holding Test and Other Factors.

<table>
<thead>
<tr>
<th>Combination of Factors</th>
<th>Correlation coefficient</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breath-holding duration : Harvard step test score</td>
<td>0.05</td>
<td>p&gt;10%</td>
</tr>
<tr>
<td>Heart rate before breath-holding : Rate of increase of heart rate during breath holding</td>
<td>0.38</td>
<td>1%&lt;p&lt;5%</td>
</tr>
<tr>
<td>Heart rate before breath-holding : Rate of decrease of heart rate after breath-holding</td>
<td>0.36</td>
<td>5%&lt;p&lt;10%</td>
</tr>
<tr>
<td>Heart rate before breath-holding : Breath-holding duration</td>
<td>0.35</td>
<td>5%&lt;p&lt;10%</td>
</tr>
<tr>
<td>Average heart rate during breath-holding : Breath-holding duration</td>
<td>0.02</td>
<td>p&gt;10%</td>
</tr>
<tr>
<td>Average heart rate during breath-holding : Harvard Step Test score</td>
<td>0.62</td>
<td>p&lt;0.1%</td>
</tr>
<tr>
<td>Breath holding duration using mercury manometer : Breath-holding duration without using mercury manometer</td>
<td>0.82</td>
<td>p&lt;0.1%</td>
</tr>
</tbody>
</table>

N = 26
The Harvard Step Test was given to 26 of the 56 subjects and simple breath-holding tests were performed. Table 2 shows the correlation coefficients between the mercury tests and simple breath-holding test without using the mercury manometer, between breath-holding duration and step test score, and others. There were high correlations between the average of heart rate during breath-holding and step test score, and also between the breath-holding duration using mercury manometer and without using mercury manometer.

From the results of the breath-holding duration and the average of heart rate during breath-holding, the T-score was drawn up as shown in Table 3.

**Table 3. T-score Tables of Breath-Holding Duration and Average of Heart Rate during Breath-Holding.**

<table>
<thead>
<tr>
<th>Breath-holding duration</th>
<th>T-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 sec.</td>
<td>30.5</td>
</tr>
<tr>
<td>20</td>
<td>34.0</td>
</tr>
<tr>
<td>25</td>
<td>37.0</td>
</tr>
<tr>
<td>30</td>
<td>40.8</td>
</tr>
<tr>
<td>35</td>
<td>44.2</td>
</tr>
<tr>
<td>40</td>
<td>47.6</td>
</tr>
<tr>
<td>45</td>
<td>51.1</td>
</tr>
<tr>
<td>50</td>
<td>54.5</td>
</tr>
<tr>
<td>55</td>
<td>58.0</td>
</tr>
<tr>
<td>60</td>
<td>61.5</td>
</tr>
<tr>
<td>65</td>
<td>64.5</td>
</tr>
<tr>
<td>70</td>
<td>68.2</td>
</tr>
<tr>
<td>75</td>
<td>71.2</td>
</tr>
<tr>
<td>80</td>
<td>75.1</td>
</tr>
<tr>
<td>85</td>
<td>77.8</td>
</tr>
<tr>
<td>90</td>
<td>81.9</td>
</tr>
</tbody>
</table>

Mean = 43.4 sec.
S.D. = 14.6

<table>
<thead>
<tr>
<th>Average of heart rate during breath-holding</th>
<th>T-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 beats/15 sec.</td>
<td>67.6</td>
</tr>
<tr>
<td>66</td>
<td>63.8</td>
</tr>
<tr>
<td>72</td>
<td>61.0</td>
</tr>
<tr>
<td>78</td>
<td>58.2</td>
</tr>
<tr>
<td>84</td>
<td>55.4</td>
</tr>
<tr>
<td>90</td>
<td>52.5</td>
</tr>
<tr>
<td>96</td>
<td>49.7</td>
</tr>
<tr>
<td>102</td>
<td>46.9</td>
</tr>
<tr>
<td>108</td>
<td>44.1</td>
</tr>
<tr>
<td>114</td>
<td>41.3</td>
</tr>
<tr>
<td>120</td>
<td>38.4</td>
</tr>
<tr>
<td>126</td>
<td>35.6</td>
</tr>
<tr>
<td>132</td>
<td>32.8</td>
</tr>
<tr>
<td>138</td>
<td>29.9</td>
</tr>
<tr>
<td>146</td>
<td>27.1</td>
</tr>
<tr>
<td>152</td>
<td>24.3</td>
</tr>
</tbody>
</table>

**Mean = 7.9 beats/5 sec.**
**S.D. = 1.2**

**Discussion**

It is generally argued that the endurance ability can be evaluated by heart rate responses and maximum oxygen consumption under the condition of maximal or submaximal exercises. Some studies\(^{(10)}\), however, have indicated that there is always the question of the degree to which the pain tolerance and physiological incompetence participate at the time when the exercises terminate.

On the other hand, the breath-holding was used in order to test aviators in World War I with loading. Flack\(^{(2)}\) used the maximum breath-holding test in 1920's with the subject
maintaining a pressure of 20mm. Hg, and in his fatigue breath-holding test, the pressure was 40mm. Hg. After Flack’s works some reporters criticized breath holding as having no values for the selection of aviators, and others found significant correlations between the physical performance and breath-holding duration.\(^{(1)(2)(3)(4)(5)}\) For these reports, Schneider\(^{(6)}\) suggested that “will power” plays an important part in the test. The author of this paper tried to use the test for well-trained athletes in order to determine whether any difference can be seen in the subjects participating in various athletic activities or not. The results showed hockey players and weight lifters were longer in breath-holding duration on the average, but it cannot be definitely said that there were significant differences in the kinds of athletic activities.

Besides the study of breath-holding duration, heart rate responses during and after breath-holding should be used for evaluation. As shown in Figure 4, it was found that the group with longer breath-holding duration was the lowest in the average of heart rate, particularly for the first 20 seconds. Statistical examination showed the average heart rate during breath-holding is closely correlated with the Harvard Step Test score. Therefore it may well be said that the heart rate response is useful for evaluation of cardiovascular fitness.

As the author of this paper mentioned in the above chapter on results, some subjects showed gradual depression of the T-wave of electrocardiogram when breath-holding began. However, most subjects showed gradual depression of the T-wave and its recovery at the time breath-holding was stopped. And a few subjects showed extrasystole immediately after the test. This fact suggests that the internal environment was strongly affected. Although Flack’s fatigue test had been used in selecting athletes, it may be said that the load of 40 mm. Hg is somewhat heavy.

In 1951 Montoye\(^{(9)}\) mentioned in his report that in devising tests for cardiovascular fitness, it should reduce or eliminate the effects of “will power” and motivation, and yet retain the circulatory stress associated with such tests. The author of this paper would like to suggest to set a limitation for breath-holding duration and to apply the heart rate responses during and after the test.

It is desirable to use heart rate responses during and after 20mm. Hg breath-holding for a maximum of 20 seconds for non-athletes, because it is usually too heavy a load to use the test for more than 20 seconds for non-athletes. Besides, the effect of “will power” is considered to be negligible within 20 seconds\(^{(8)}\).

Conclusions

There are some conclusions drawn from this study.

(1) Those who held long breath-holding duration showed the periodical variation of the heart rate, from 10 to 20 second, during breath-holding.

(2) In the group with longer breath-holding duration, the average heart rate during breath-holding was low.
The correlation was found high between breath-holding using mercury manometer and without mercury manometer. And the correlation was also found high between the average heart rate during breath-holding and Harvard Step Test score.

It is concluded that heart rate during breath-holding and breath-holding duration in the mercury test will be useful as an evaluation factor for athletes.

It is desirable to use heart rate responses during and after 20mm. Hg breath-holding for a maximum of 20 seconds for non-athletes.

References

13) Schneider E. C. and P. V. Karpovich, Physiology of Muscular Activity, W. B. Saunders Co. 1948, pp. 265-266.