EXERCISE, BODY BUILD AND ELECTROCARDIOGRAM
–THE INFLUENCES OF SPORTS
AND TRAINING ON THE ELECTROCARDIOGRAM–

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It is well known that the degree of sports and/or the hardness of training required by the sports exert several influences upon the heart and so the electrocardiogram. The characteristic items of the electrocardiogram which have been observed in sportsmen are as follows: sinus bradycardia, PQ-prolongation, incomplete right bundle branch block, and the increase in the amplitudes in each lead, especially in the precordial leads.\(^1,2\)

The electrocardiogram records potentials caused by the cardiac electromotive forces on the body surface and, therefore, if the degree of sports and their training have more or less some influence on the heart, the electromotive forces of the heart may be expected to increase and accordingly the increase in the amplitudes of the R waves may also be expected. But these relationships are not necessarily simple. For example, the increase of chest size due to hard training may decrease the amplitudes of the R waves recorded on the body surface.

The electrocardiographic manifestations of the sportsman’s heart would be incomplete right bundle branch block on the right chest and the increase in the amplitudes of the R waves of leads \(V_5\sim6\) on the left chest, respectively. Therefore, in the present study, the relationship between the amplitudes of the R and T waves of lead \(V_5\) and the degree of sports and/or hardness of training required by the sports will be elucidated in several aspects by means of multivariate analysis.

MATERIALS AND METHODS

The materials consist of 278 males and 168 females of about 20 years of age as shown in Table I. The greater part of the subjects are college students. The subjects corresponding to those who occupy the section "/'" in the second column of this table do not belong to any athletic club at all, those corresponding to the section "hard" belong to athletic clubs which require hard training such as Rugby, Soccer, Judô, and field and track events, and those corresponding to the section "not hard" are those who belong to other departments of sports which are thought to be not hard in training. Thus the male subjects were divided into 3 groups and the female into 2 groups. In Table II are shown the means and standard deviations of the amplitudes of the R and T waves of leads II, aVF, \(V_4\), \(V_5\) and \(V_6\) in each group. In the first place the means, standard deviations and standard errors of the amplitude of the R wave of lead \(V_5\) in each group are shown in Fig. 1 for the sake of grasping the general trend. A similar figure concerning the T wave can be obtained (not illustrated). Nextly, to examine the influences of body height and weight on the amplitude of the R wave of lead \(V_5\), the 3 groups of male subjects and the 2 groups of female subjects were gathered together respectively. Thus the total subjects were divided into 2 groups only according to sex, and each group was divided into 4 subgroups in correspondence to means ± standard errors of body height and weight respective-

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TABLE I SEX, BODY BUILD, DEGREE OF HARDNESS OF SPORTS, AND MEANS (M) AND STANDARD DEVIATIONS (S.D.) OF PARAMETERS EXPRESSING BODY BUILD

<table>
<thead>
<tr>
<th>Sex</th>
<th>degree of hardness of sports</th>
<th>body height (cm)</th>
<th>body weight (kg)</th>
<th>chest circumference (cm)</th>
<th>sitting height (cm)</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>S.D.</td>
<td>M</td>
<td>S.D.</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>168.7</td>
<td>5.2</td>
<td>58.2</td>
<td>6.3</td>
<td>85.8</td>
</tr>
<tr>
<td>male</td>
<td>not hard</td>
<td>168.9</td>
<td>4.9</td>
<td>59.5</td>
<td>6.5</td>
<td>87.5</td>
</tr>
<tr>
<td></td>
<td>hard</td>
<td>169.1</td>
<td>5.3</td>
<td>62.3</td>
<td>8.0</td>
<td>89.9</td>
</tr>
<tr>
<td>female</td>
<td></td>
<td>155.6</td>
<td>5.0</td>
<td>52.3</td>
<td>6.5</td>
<td>82.5</td>
</tr>
<tr>
<td></td>
<td>not hard</td>
<td>156.7</td>
<td>4.2</td>
<td>51.6</td>
<td>4.4</td>
<td>82.4</td>
</tr>
</tbody>
</table>

Fig. 1. Comparison of the amplitude of RV₅ (mm) in each group.

ly, and the differences of the mean values of the amplitude of the R wave of lead V₅ in each subgroup were tested as indicated in Fig. 2. In this case the points on the borderline were treated as affiliated with corresponding subgroups. In the male subjects classified into 4 subgroups according to the body weight and chest circumference the same procedure was carried out (Fig. 3). G₁, G₂, G₃ and G₄ in Figures 2 and 3 were used only in these 2 figures and differed from G₁, G₂ etc., which appeared in Fig. 1.

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TABLE II MEANS (M) AND STANDARD DEVIATIONS (S.D.) OF SEVERAL ELECTROCARDIOGRAPHIC DEFLECTIONS FOR 446 HEALTHY MALES AND FEMALES OF ABOUT 20 YEARS OF AGE BY DEGREE OF HARDNESS OF SPORTS AND SEX GROUPS

<table>
<thead>
<tr>
<th>Sex</th>
<th>male</th>
<th>male</th>
<th>male</th>
<th>female</th>
<th>female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>S.D.</td>
<td>M</td>
<td>S.D.</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RII</td>
<td>13.31</td>
<td>5.21</td>
<td>15.25</td>
<td>4.46</td>
<td>15.18</td>
</tr>
<tr>
<td>TII</td>
<td>3.68</td>
<td>1.55</td>
<td>4.47</td>
<td>1.54</td>
<td>4.58</td>
</tr>
<tr>
<td>RaVF</td>
<td>10.91</td>
<td>5.09</td>
<td>13.21</td>
<td>4.85</td>
<td>12.63</td>
</tr>
<tr>
<td>TaVF</td>
<td>2.51</td>
<td>1.20</td>
<td>2.98</td>
<td>1.31</td>
<td>2.92</td>
</tr>
<tr>
<td>RV4</td>
<td>17.61</td>
<td>7.17</td>
<td>20.63</td>
<td>6.15</td>
<td>19.46</td>
</tr>
<tr>
<td>TV4</td>
<td>8.13</td>
<td>3.44</td>
<td>9.39</td>
<td>3.52</td>
<td>8.49</td>
</tr>
<tr>
<td>RV5</td>
<td>15.68</td>
<td>6.77</td>
<td>19.70</td>
<td>5.18</td>
<td>18.40</td>
</tr>
<tr>
<td>TV5</td>
<td>5.76</td>
<td>3.04</td>
<td>7.33</td>
<td>2.71</td>
<td>6.85</td>
</tr>
<tr>
<td>RV6</td>
<td>11.88</td>
<td>5.35</td>
<td>14.59</td>
<td>4.22</td>
<td>13.78</td>
</tr>
<tr>
<td>TV6</td>
<td>3.69</td>
<td>1.99</td>
<td>4.77</td>
<td>1.81</td>
<td>4.57</td>
</tr>
</tbody>
</table>

Lastly regression analysis was performed with RV₅ as a random variable and four parameters showing body build, namely, body height, body weight, chest circumference, sitting height and all the functions such as, for example, geometrical products, squares, and their reciprocals as fixed variables. Because the degree of sports and/or hardness of training exert influences upon the parameters showing the body build significantly, the relationship between RV₅ and these parameters ought to be elucidated, for example, by means of regression analysis. However these parameters, as a matter of course, correlate with one another and so multicollinearity exists. This multicollinearity among the fixed variables is not favorable in linear regression analysis and, therefore, selecting-variable procedures of regression analysis of Draper and Smith³ were accepted and the best regression equations were obtained in the present study. Both stepwise regression procedure and backward elimination procedure were used. These procedures were explained in our previous paper.⁴ Accordingly we refer the investigators who are interested in the mathematical details to this paper and the monograph of Draper and Smith.

In this study the accepted fixed variables are the same as in the previous paper.⁴ As for the random variable the following 4 were considered:

1. RV₅
2. RV₅ x (sitting height x chest depth)
3. RV₅ + SV₁
4. (RV₅ + SV₁) x (sitting height x chest depth)

The reason of considering these 4 cases is as follows:

If the cardiac electromotive force is due to a dipolar generator, the component of the dipole moment is dependent on the body surface area orthogonal to this component according to the considerations of Barber and Fischmann⁵ and Nelson et al.⁶

RESULTS

As shown in Table II, and Figures 1 and 2, the sex differences of RV₅ and TV₅ are significant. In the 3 male groups (G₁, G₂ and G₃) these amplitudes are significantly smaller in the group not engaged in any sport (G₁) than the groups engaged in sports (G₂ and G₃), but in the 2 female groups the significant differences in these amplitudes are not observed. As for the 2 male groups engaged in sports the amplitudes of both RV₅ and TV₅ are smaller in the group requiring hard training (G₃) than in the group G₂. Fig. 2 which indicates the relationship between RV₅, and body height and body weight elucidates eventually the influence of body weight on RV₅ because the 4 parameters showing the body build

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do not disclose significant differences between the 2 female groups and the 2 parameters of body weight and chest circumference exhibit significant differences among the 3 male groups as clearly shown in Table I. This relationship between RV₅ and body weight has almost the same tendency in both sexes, and the larger the body weight is, the tendency for RV₅ to become

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greater exists. The significant differences between \( G_1 \) and \( G_2 \) in the male and between \( G_2 \) and \( G_4 \) in the female are observed (as previously mentioned, the meaning of suffixes of \( G \), only in the Figures 2 and 3, differ from that of Fig. 1). This fact indicates that when the body height is greater as compared with the body weight the amplitude of RV₄ becomes smaller. Because the amplitude of RV₄ and the 4 parameters showing the body build did not show any significant difference between the 2 female groups, these 2 groups were considered homogeneous and so treated in the lump, but all the subjects of the 3 male groups were divided into 4 groups by 2 parameters, i.e., body weight and chest circumference exhibiting significant differences for the purpose of examining the relationship between RV₅ and these 2 parameters. As shown in Fig. 3, RV₅ of the group having the greater values of both body weight and chest circumference is significantly greater as compared with the other groups. Namely, from the above-mentioned result, RV₅ in the subjects with a robust body build is greater than in the other groups. But the significant differences exist between the groups \( G_2 \) and \( G_3 \) concerning the body weight and the chest circumference as shown in Table I. In the latter, i.e., in the group engaged in hard training, these parameters showing this body build become significantly greater and this group has a robust body build, but the amplitudes of both RV₅ and TV₅ are significantly smaller in this group \( G_3 \). Therefore, by multiplying RV₅ and (RV₅ + 5V₄) by body surface area (sitting height x chest depth was accepted as an approximate value), the random variables were transformed, and selecting-variable procedure of regression analysis was performed with respect to both the original and transformed random variables. The results of both stepwise regression procedure and backward elimination procedure were almost the same. The result of stepwise regression procedure was shown in the previous paper. The comparison of the F values gives the highest value to the case of RV₅ x (sitting height x chest depth) but in this case the random variable is combined with the fixed variable and so this situation is not necessarily favorable. Accordingly, we accepted RV₅ as a random variable. In this case the F-value with respect to the body weight was the largest.

**DISCUSSION**

It was previously pointed out that the electrocardiogram showed the differences due to age, sex, body build and engagement of sports, and, if the subject is engaged in any sports, the degree of sport and/or the hardness of training needed for the sportι, 2, 4, 7, 8. The increase of the R waves, especially the increase of those in the precordial leads, could be expected because the sport and training produce physiological hypertrophy of the heart and, accordingly, the increase in the cardiac electromotive forces.

In the 2 female groups \( (G_4 \text{ and } G_5) \) both R and T waves generally do not show significant differences, but in the 2 male groups \( (G_1 \text{ and } G_2 \text{ and } G_3) \) these waves show significant differences between two groups, i.e., \( G_1 \text{ and } G_2 \) and \( G_3 \). However, as opposed to the expectation from the physiological hypertrophy of the heart in the subjects engaged in sports requiring hard training \( (G_3) \), RV₅ in this group is not the largest, but that in the subjects engaged in sports requiring not so hard training \( (G_2) \) is the largest of all the 3 groups \( (G_1 \text{, } G_2 \text{ and } G_3) \), and this R wave exhibits significant differences among these 3 groups. If the electrocardiogram is assumed to directly reflect the physiological hypertrophy of the heart, this result could not be explained. The fact that RV₅ in the 2 female groups shows no significant difference could be understood by the absence of the significant differences among the 4 parameters showing the body build and also by a small amount of the degree and hardness of sports, but in the 2 male groups \( (G_2 \text{ and } G_3) \) significant differences of the mean values of body height and sitting height do not exist but the mean values of body weight and chest circumference show significant differences (greater in \( G_3 \) than in \( G_2 \)). This fact shows that training makes the body build robust.

It is postulated that the cardiac electromotive forces themselves do not appreciably change with age and the decrease of potentials recorded on the body surface with age could be accounted for by the increase of the body build, based upon the consideration of changes of the vectorcardiogram with age according to the dipole hypothesis. According to this hypothesis the following explanation is plausible. The amplitude of RV₅ is significantly smaller in the group who engages in sports requiring hard training \( (G_3) \) than in the group \( G_2 \), but the body weight and chest circumference are significantly greater in \( G_3 \) than in \( G_2 \). This is probably due to the fact that the increase in the cardiac electromotive forces due to sports and training could be assumed to be decreased by the increase in torso
as a volume conductor with increasing body build. And also RV₅ in the Group G₂ is the largest of all these 3 male groups and the body weight and chest circumference in this group are intermediate among these 3 groups. In the group G₂ the electromotive forces are to some extent increased by sports and training but the degree of increase in body build (increase in torso volume) is not so great as in the group G₃, and so the decrease of the potentials recorded on the body surface could be expected relatively small in this group. Therefore RV₅ is the greatest of all the 3 groups probably due to a relatively small increase in torso volume and a moderate increase in the cardiac electromotive forces. However, sports and training clearly increase the cardiac electromotive forces and so the amplitude of RV₅ because RV₅ is significantly greater in the group engaged in sports than in the group engaged not in any sports whatever the degree of sports and/or the hardness of training may be great or small. The relationship between the amplitude of RV₅ and the body build and, accordingly, that between RV₅ and training could be presumed from the Figures 2 and 3. In Fig. 2, in the male subjects at the same level of the body height RV₅ becomes the greater the more the body weight is, and in Fig. 3 the more the body weight and chest circumference are. However, in Figures 2 and 3, all the subjects constituting G₁, G₂ and G₃ are divided in a different manner into 4 groups. The comparison of these figures with Table I discloses that the subjects with greater body weight and chest circumference correspond to those engaged in any sports. Therefore, from these figures, it is concluded that sports increase the amplitude of RV₅. Accordingly, with RV₅ itself or RV₅ corrected by the body build as a random variable and several constitutional variables as fixed variables, selecting-variable procedure of regression analysis was performed. The result of this procedure is that RV₅ correlates most closely with the body weight.

In summarizing the above results, RV₅ is smaller in subjects engaged in sports requiring hard training than in those not needed for hard training and this may be assumed to be due to the decrease of potentials of the cardiac electromotive forces recorded on the body surface by the increase of the torso volume (increase of the body weight) concomitant with the degree of sports and/or the hardness of training.

CONCLUSION

The influence of the degree of sports and/or the hardness of training on the amplitude of RV₅ was chiefly examined in about 20 year old healthy subjects of both sexes without cardiac disease. The male subjects were divided into 3 groups including one group that did not engage in any sport. The female subjects were divided into 2 groups. In the female, one group did not also engage in any sport.

1. In the 2 female groups both RV₅ and 4 parameters showing the body build do not show significant differences. This is probably because in the female subjects the degree of sports and/or the hardness of training is not so great as in the male subjects.

2. In the male subjects the amplitude of RV₅ is significantly greater in the groups that engage in sports (G₂ and G₃) than in the group that does not engage in any sport. Out of the parameters showing the body build, the body weight fairly correlates with RV₅ and the greater the amplitude of RV₅ becomes the more the body weight is.

3. In the 2 male athletic groups, the amplitude of RV₅ is significantly greater in G₂ than in G₃ and, with respect to the parameters showing the body build, both body weight and chest circumference are significantly greater in G₃ than in G₂. Namely, in the group engaged in sports requiring hard training, each subject has a robust body build but the amplitude of RV₅ does not become so great as expected. This is probably because the cardiac electromotive forces are increased to a certain extent by exercise and the human torso volume as a volume conductor is also augmented due to the increase in both the body weight and the chest circumference according to the degree of sports and/or the hardness of training so that the increase in the amplitude of RV₅ is to some degree cancelled out by the simultaneous increase in the torso volume.

4. The sex differences in the electrocardiogram in subjects of about 20 years of age are significant. In the proper interpretation of the electrocardiogram not only the sex differences but also the differences of the body build, especially those of the body weight, the chest circumference, the engagement of sports, and, if the subject is engaged in any sport, the degree of sports and/or the hardness of training should be all taken into consideration.

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