Effect of Voluntary Exercise on Maximal Oxygen Uptake in Young Female Fischer 344 Rats

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Summary: The effect of voluntary exercise on maximal oxygen uptake ($V_{O_2,\text{max}}$) was studied in young female Fischer 344 rats. After 10 weeks of wheel-running training, the absolute $V_{O_2,\text{max}}$ and $V_{O_2,\text{max}}$ relative to body mass increased without a decline in body mass. The running speed eliciting $V_{O_2,\text{max}}$ heart and soleus muscle mass, and succinate dehydrogenase (SDH) activity in the soleus muscle also increased. These results suggest that voluntary exercise is an effective means of increasing the aerobic exercise capacity of young female Fischer 344 rats. [Japanese Journal of Physiology, 47, 139–141, 1997]

Key words: absolute $V_{O_2,\text{max}}$, relative $V_{O_2,\text{max}}$, wheel running, exercise training.

Forced exercise training with a motor-driven treadmill is frequently used to analyze the effect of training on the aerobic exercise capacity of experimental animals [1–3]. Maximal oxygen uptake ($V_{O_2,\text{max}}$), as an index of aerobic exercise capacity, increases in absolute ($V_{O_2,\text{max}}$(ml · min⁻¹)) and relative terms ($V_{O_2,\text{max}}$(ml · min⁻¹ · kg⁻¹)) after forced exercise training [1, 2].

Recently, voluntary exercise involving wheel running has also often been used in animal experiments for exercise training [4–6]. Heart mass [5], skeletal muscle mitochondrial enzymes [6], and relative $V_{O_2,\text{max}}$ increase after voluntary exercise suggest an increase in aerobic capacity. However, there is a possibility that the increase in relative $V_{O_2,\text{max}}$ is not substantial and may be secondary to the loss of body mass during training [4]. Since exercise training is performed mostly by young experimental animals, a rapid change in body mass in the growth phase and the effect of exercise on it alter the relative $V_{O_2,\text{max}}$ values. A substantial change in aerobic capacity is, therefore, better evaluated by both the absolute and relative $V_{O_2,\text{max}}$ values, preferably in an animal species which exhibits no significant decrease in body mass after training. The aim of this study was to verify the effect of voluntary exercise on the aerobic capacity of female Fischer 344 rats. Previous studies have already shown that there is no change [2] or increase [7] in body mass following forced exercise training in this species.

Four-week-old female Fischer 344-strain (62–67 g) rats were provided with pellet chow and water ad libitum. Control rats were placed individually in standard laboratory cages, while voluntarily exercised rats were placed individually in activity cages in which they could exercise voluntarily all day using a rotatory wheel. After a 10-week wheel-running period, the $V_{O_2,\text{max}}$ levels in the voluntarily exercised and control rats were measured using the rapid-flow open-circuit system described previously by Yano and Nagao [8]. Three days after the $V_{O_2,\text{max}}$ test, all animals were sacrificed under pentobarbital anesthesia (60 mg · kg⁻¹). The soleus muscle was quickly frozen in liquid nitrogen and stored at −80°C for determination of the activity of succinate dehydrogenase (SDH) [9]. Data were reported as the mean±SE. The differences between the voluntarily exercised and control rats were analyzed using a Mann-Whitney U-test.

Changes in the voluntary wheel activity of rats over 10 weeks agree well with previous studies on young rats (Fig. 1) [4, 5]. After the 10-week wheel-running period, the body mass and food intake of the voluntarily exercised rats were significantly higher than those of the control group. Both absolute and relative $V_{O_2,\text{max}}$...
were observed to be higher in the voluntarily exercised rats than in the control group. In addition, the running speed eliciting \( \dot{V}_{\text{O}_2 \text{max}} \), heart and soleus muscle mass, and SDH activity in the soleus muscle was higher than that in the control rats (Table 1).

In the developmental phase, the level of relative \( \dot{V}_{\text{O}_2 \text{max}} \) was strongly affected by the body mass of the rats [8], but a loss of body mass due to the physiologic stress of the exercise did not occur in the young female Fischer 344 rats [7]. Accordingly, the increase in relative \( \dot{V}_{\text{O}_2 \text{max}} \) with voluntary exercise was not affected by body mass. Therefore, this study clarified that voluntary exercise is an effective means of increasing \( \dot{V}_{\text{O}_2 \text{max}} \) substantially in young female Fischer 344 rats.

The running speed eliciting \( \dot{V}_{\text{O}_2 \text{max}} \) has been a frequently reported measure of aerobic power [1, 2]. Previously, the running speed elicitating \( \dot{V}_{\text{O}_2 \text{max}} \) was found to correlate with the absolute \( \dot{V}_{\text{O}_2 \text{max}} \) but not with the relative \( \dot{V}_{\text{O}_2 \text{max}} \) of rats in the developmental phase [8]. An adaptive response to aerobic capacity and the elevation of physical performance might be acquired by voluntary wheel running for 10 weeks.

The effect of endurance exercise training is reflected in increases in heart [5] and skeletal muscle [10] mass and the mitochondrial oxidative capacity of skeletal muscle [1, 6, 10]. Our results suggest that 10-week voluntary exercise was enough for endurance exercise training. These findings might explain the increase in substantial \( \dot{V}_{\text{O}_2 \text{max}} \). While no differences existed between control and forced exercise training at 75% \( \dot{V}_{\text{O}_2 \text{max}} \) for 8 weeks at 1 h · d\(^{-1} \) [2], the heart mass of the voluntarily exercised rats was significantly greater than that of the control group in the young female Fischer 344 rats. It is possible that the wheel-running speed and distance ran by the rats were greater than that of forced exercise with a treadmill, but it is likely that the running was of shorter duration [4, 6]. At 9 weeks of age, in fact, the running distance of the voluntarily exercised rats was 8.4-fold longer than that of rats doing forced exercise in the study of Mazzio et al. (13.5 (our study) and 1.6 km · d\(^{-1} \) [2], respectively).

It was concluded that voluntary exercise increases \( \dot{V}_{\text{O}_2 \text{max}} \) substantially, and that it is an effective means of aerobic exercise training for young female Fischer 344 rats.

We thank Dr. N. Nagao, Dr. S. Onodera, and Mr. D. H. Waterbury for reading the manuscript and for their useful suggestions.

![Fig. 1. Changes in voluntary wheel-running activity of female Fischer 344 rats (n=6) during the developmental phase. The values of cage revolutions for each week are the means±SE.](image)

Table 1. Effect of voluntary exercise on characteristic physical parameters in young female Fischer 344 rats.

<table>
<thead>
<tr>
<th>n</th>
<th>Body mass (g)</th>
<th>( \dot{V}_{\text{O}_2 \text{max}} ) (mL/min)</th>
<th>( \dot{V}_{\text{O}_2 \text{max}} ) (mL/min/kg)</th>
<th>Running speed eliciting ( \dot{V}_{\text{O}_2 \text{max}} ) (m/min)</th>
<th>Food Intake (g/d)</th>
<th>SDH activity in soleus muscle (( \mu \text{mol/min/g tissue} )</th>
<th>(( \mu \text{mol/min/mg protein} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (6)</td>
<td>157±1</td>
<td>9.3±0.2</td>
<td>61.2±2.1</td>
<td>39.3±1.0</td>
<td>9.9±0.1</td>
<td>SDH activity in soleus muscle</td>
<td>SDH activity in soleus muscle</td>
</tr>
<tr>
<td>VE (6)</td>
<td>162±2*</td>
<td>12.2±0.7**</td>
<td>74.0±3.9*</td>
<td>61.4±1.8**</td>
<td>15.9±0.6**</td>
<td>SDH activity in soleus muscle</td>
<td>SDH activity in soleus muscle</td>
</tr>
<tr>
<td>n</td>
<td>Heart mass (g)</td>
<td>Soleus muscle mass (mg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (6)</td>
<td>0.56±0.02**</td>
<td>77±2</td>
<td>1.1±0.2</td>
<td>7.6±2.0</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>VE (6)</td>
<td>0.69±0.02**</td>
<td>97±6**</td>
<td>2.7±0.3**</td>
<td>18.2±3.0**</td>
<td></td>
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</tr>
</tbody>
</table>

Values are the means±SE. Statistically significant voluntary exercise effect (versus the values in control rats): *p<0.05, **p<0.01. C, control group; VE, voluntary exercise group.
Voluntary Exercise Affects $\tilde{V}_{O_2}$max in Rats

REFERENCES