A Preliminary Exercise Study of Japanese Version of High-intensity Interval Aerobic Training (J-HIAT)

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In a microgravity environment, the volume load on the left ventricle is reduced and the cardiac function deteriorates. Consequently, maximal oxygen consumption ($V_\text{O}_2\text{max}$) decreases during spaceflight. Reduced cardiac function can lead to serious health problems such as cardiac atrophy, diastolic dysfunction, and orthostatic hypotension. An exercise using a bicycle ergometer during spaceflight may help to increase the volume load on the left ventricle. On the other hand, many astronauts also experience weight loss during spaceflight because energy imbalances can occur. Some researchers indicate that excessive exercise may promote the energy deficit and have a negative impact on long-term spaceflight. Therefore, we have been devising an original bicycle ergometer protocol better suited to astronauts experiencing long-term spaceflight.

One of our candidate protocols is the 3 × 3 protocol named J-HIAT, i.e., three times 3-min intervals with a 2-min active recovery period between intervals. In response to our preliminary experiments, we concluded that J-HIAT would be a potential protocol to control the increase of energy consumption and to have a significant impact on $V_\text{O}_2\text{max}$ and the cardiac function. To further verify this method, we are working on full-scale experiments. In future, we will show the results of these experiments.

Key Words: Microgravity, Cardiac Function, Maximal Oxygen Consumption

1. Introduction

For astronauts staying in space, it is important to keep their activity there healthy, safe and comfortable. Understanding the influences of environmental stress on astronauts during space flight is a major focus of space medicine. The purpose of the space medicine is to improve performance associated with an astronaut’s long stay in space. Against such background, we, the Japan Aerospace Exploration Agency (JAXA) Space Biomedical Research Office (J-SBRO), are trying to understand and address the influences of the space environment on human health.

In a microgravity environment, the volume load on the left ventricle is reduced and the cardiac function deteriorates 1). Consequently, the maximal oxygen consumption ($V_\text{O}_2\text{max}$), which is used to evaluate the cardiovascular function and relates directly to a human’s physical working capacity, decreases during spaceflight 2). Reduced cardiac function can lead to serious health problems such as cardiac atrophy, diastolic dysfunction, and orthostatic hypotension. An exercise using a bicycle ergometer during spaceflight may help to increase the volume load on the left ventricle. On the other hand, many astronauts also experience weight loss during spaceflight because energy imbalances can occur, i.e., an astronaut’s total energy expenditure may exceed his/her total energy intake 3). Therefore, some researchers indicate that excessive exercise may promote the energy deficit and have a negative impact on long-term spaceflight 4).

High-intensity interval aerobic training (HIAT), which is an activity conducted within a short period of time but which has a strong impact on the heart 5,6), is a potential countermeasure. Previous studies 5,6) describe several HIAT protocols designed specifically for athletes. We hypothesize that these HIAT protocols can control the increase of energy consumption and prevent the deterioration of the cardiac function and are hence trying to devise an original HIAT protocol better suited to astronauts experiencing long-term spaceflight and verify its effectiveness and appropriateness through ground-based experiments.

For this purpose, we are planning to complete three ground-based experiments as follows:

1) A preliminary experiment: to devise an original HIAT protocol named J-HIAT.
2) Experiment 1: to compare the total energy consumption (expenditure) using J-HIAT with those of the other protocols.
3) Experiment 2: to compare the effects of J-HIAT on $V_\text{O}_2\text{max}$ and cardiac function with those of the other protocols.

First of all, in this paper, we show some results of the preliminary experiment.

2. Methods

2.1. Devising an original HIAT protocol (J-HIAT)

Previous studies 5,6) indicated that one of the representative examples of the HIAT for improving cardiac function is the 4 × 4 protocol, i.e., four times 4-min intervals with HR at 90%
of maximum HR, with a 3-min active recovery period at ~70% of maximum HR between intervals. However, our own exercise trials revealed several co-workers (healthy young men) were unable to complete the protocol. Therefore, we considered that the 4 × 4 protocol might be too much for non-athletes (including astronauts). Also, with the total energy expenditure in mind, we wanted to shorten the total exercise duration as well as possible.

After our own exercise trials, we determined our original HIAT protocol (J-HIAT). Table 1 shows the detailed contents of the J-HIAT.

### Table 1. Contents of the J-HIAT.

<table>
<thead>
<tr>
<th>Contents</th>
<th>Total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Warm up</td>
<td>2 min</td>
</tr>
<tr>
<td>II. Interval training</td>
<td>18 min</td>
</tr>
<tr>
<td>3 min (85~90%VO\text{\textsubscript{2}}max)</td>
<td></td>
</tr>
<tr>
<td>2 min (50%VO\text{\textsubscript{2}}max)</td>
<td></td>
</tr>
<tr>
<td>3 min (85~90%VO\text{\textsubscript{2}}max)</td>
<td></td>
</tr>
<tr>
<td>2 min (50%VO\text{\textsubscript{2}}max)</td>
<td></td>
</tr>
<tr>
<td>3 min (80~85%VO\text{\textsubscript{2}}max)</td>
<td></td>
</tr>
<tr>
<td>III. Cool down</td>
<td>3 min</td>
</tr>
</tbody>
</table>

2.2. Subjects for the preliminary experiments

Two sedentary subjects participated in the preliminary experiments. Table 2 shows the characteristics of the 2 subjects.

### Table 2. Characteristics of the subjects.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Body weight, kg</th>
<th>Body mass index, kg/m\textsuperscript{2}</th>
<th>VO\text{\textsubscript{2}}max, L/min</th>
<th>VO\text{\textsubscript{2}}max, ml/kg・\textsubscript{min}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>36</td>
<td>172.0</td>
<td>71.0</td>
<td>24.0</td>
<td>2638</td>
<td>37.2</td>
</tr>
<tr>
<td>B</td>
<td>27</td>
<td>164.0</td>
<td>59.0</td>
<td>21.9</td>
<td>3324</td>
<td>56.3</td>
</tr>
</tbody>
</table>

2.3. Energy expenditure measurement

Initially, we measured subjects’ energy expenditure, both during and after (3 hours) the exercise (J-HIAT). Gas exchanges (oxygen uptake and carbon dioxide production) during and after exercise were measured by indirect calorimetry (AE-310S, MINATO, Japan) (Fig. 1). Energy expenditure was estimated from the oxygen uptake and carbon dioxide production using Weir’s equation. 7)

2.4. Intervention

Next, the subjects were involved in a 2-week exercise intervention program consisting of the J-HIAT (5 times per week; total 10 times). We measured subjects’ VO\text{\textsubscript{2}}max at the baseline and post-intervention.

Fig. 2. Two subjects participated in the J-HIAT intervention program (5 days per week). VO\text{\textsubscript{2}}max was measured before and after the intervention.

3. Results and Discussion

3.1. Energy expenditure by J-HIAT

When we discuss issues concerning energy expenditure by exercise, we need to consider not only the exercise duration but also a post-exercise recovery period. During this period, there is increased oxygen uptake termed the ‘excess post-exercise oxygen consumption (EPOC)’. A review paper 8) regarding EPOC indicates that a curvilinear relationship between the magnitude of EPOC and the intensity of the exercise bout has been found, whereas the relationship between exercise duration and EPOC magnitude appears to be more linear. The J-HIAT includes a relatively higher exercise intensity and a shorter exercise duration compared to a traditional exercise protocols (e.g., 30-min at 60% of VO\text{\textsubscript{2}}max). With this in mind, we should know the energy expenditure of the J-HIAT, including its EPOC. Both Fig. 3 and Table 3 show subjects’ energy expenditure both during and after the J-HIAT. These results indicate that the J-HIAT’s intensity may not have a strong impact on its EPOC.

Fig. 3. Subjects’ energy expenditure during and after the exercise. RMR: resting metabolic rate.
Fig. 4. A view showing a frame format of subjects’ energy expenditure during and after the exercise.

Table 3. Total energy expenditure during exercise and the EPOC.

<table>
<thead>
<tr>
<th>Area</th>
<th>Subject A</th>
<th>Subject B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise (18 min), kcal</td>
<td>130</td>
<td>163</td>
</tr>
<tr>
<td>EPOC (180 min), kcal</td>
<td>18</td>
<td>11</td>
</tr>
</tbody>
</table>

3.2. Effects of the J-HIAT on $\text{VO}_2\text{max}$

Fig. 5 shows the effects of the J-HIAT on $\text{VO}_2\text{max}$ in both subjects A and B. Despite the short intervention (2 weeks), significant increases in $\text{VO}_2\text{max}$ were observed in both subjects. The results indicate that the J-HIAT may have a substantial influence on improved $\text{VO}_2\text{max}$.

4. Conclusion

In response to the results of the preliminary experiment, we concluded that J-HIAT would be a potential protocol to control the increase of energy consumption and to have a significant impact on $\text{VO}_2\text{max}$ and the cardiac function.

To further verify this method, we are working on experiment 1 (i.e., a cross-over design study to compare the energy expenditure of the J-HIAT with that of the other protocols) and experiment 2 (i.e., an intervention study to compare the effects of the J-HIAT on $\text{VO}_2\text{max}$ and cardiac function with those of the other protocols). In future, we will show the results of both experiments 1 and 2.

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References