Prescription for Rehabilitative Two-step Exercise with a Low-level Treadmill Exercise Testing in Cardiac Patients

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The aim of the present study is to design a new protocol of low-level treadmill exercise testing suitable for an evaluation of exercise tolerance capacity in patients convalescing from acute myocardial infarction and also to determine the two-step exercise equivalent in energy cost to treadmill exercise of various levels of work load.

The whole material consisted of 42 healthy men aged from 24 to 37. They conducted a low-level treadmill exercise testing consisting of 5 stages, which began with the belt speed (v mph) = 1.0 and the slope (G%) = 0 in the first stage and went up to 2.5-mph speed and 12% slope in the fifth one. They also performed 6 stages of intermittent two-step exercise on a Master's original staircase at 10 to 60 trips per 3 min. Thirty and eleven men of the study material exercised on 3 two-step staircases, which differed in the step height (15, 19 and 22.9 cm), at 30 trips and at 20, 30 and 40 trips per 3 min, respectively.

The energy expenditure of the low-level treadmill exercise was expressed in the following formula obtained from the data on the whole material: oxygen uptake (Vo2, ml/kg·min) = 8.29 + 0.98v² + 0.25v·G, with r = 0.90 (p < 0.01) and SEE = 2.13. In two-step exercise on a Master's original staircase, Vo2 showed a significant linear correlation with the number of trips per minute (t) (r = 0.96, p < 0.001): Vo2(ml/kg·min) = 6.85 + 1.17f, with SEE = 1.84. There was also a significant linear correlation between Vo2 and the height of the step (h cm) in the data from the 30 men (r = 0.77, p < 0.01), the regression equation being Vo2(ml/kg·min) = 5.21 + 0.58h. The results from the 11 men showed that Vo2 could be expressed as a function of f and h in two-step exercise; Vo2(ml/kg·min) = 6.10 + 0.05f-h was obtained with SEE = 1.47 (r = 0.90, p < 0.01).

The heart rate (HR) significantly correlated with Vo2 in both treadmill (r = 0.70, p < 0.01) and two-step (r = 0.84, p < 0.01) exercise. The regression equation was HR = 68.3 + 2.11 Vo2 (SEE = 10.5) in treadmill exercise, and HR = 63.1 + 2.53 Vo2 (SEE = 11.4) in two-step exercise. The excellent similarity observed in these 2 equations indicates that the heart rate response is nearly identical in these 2 modalities of exercise when O2 uptake is the same.

A new protocol of a low-level multistage treadmill exercise testing was designed, in which the energy cost was 2.5 METs in the first stage and 3 METs in the second one, and subsequently, its increment was 1 MET between the 2 neighbouring stages. The two-step exercise which corresponded in energy cost to each stage of the low-level treadmill exercise protocol was tabulated with the number of trips under 3 different staircases. These data could provide necessary information in comparing the results of these 2 modalities of exercise and also in performing rehabilitative exercise over a two-step staircase after exercise prescription made with a low-level treadmill exercise testing, the latter of which is the ultimate purpose of the present study.

Key Words:
Oxygen uptake, Low-level treadmill exercise testing, Two-step exercise, Cardiac rehabilitation, Circulatory response to exercise

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Clinical importance of cardiac rehabilitation has been widely recognized in our country in recent years. Rehabilitative programs for patients convalescing from acute myocardial infarction usually consist of low- to moderate-level dynamic leg exercise such as walking and/or climbing stairs. In such patients who have been forced to immobilization for a while, optimal exercise prescription is essential, which should be adequate enough in both the intensity and duration to physically recondition them without overstressing their healing heart. A motor-driven treadmill seems to be a suitable means for both exercise prescription and actual rehabilitative exercise but has disadvantages of its expensiveness and complicated structure. On the other hand, being simple and inexpensive, a two-step staircase seems to be a useful apparatus in cardiac rehabilitative exercise but has a definite shortcoming of its inherent infeasibility for in-exercise measurement of blood pressure which is indispensable for adequate exercise prescription. Thus, the authors intended to establish a rehabilitative exercise program with a reasonable cost-benefit relation, in which the evaluation of exercise tolerance and exercise prescription were made with treadmill exercise testing, and patients were exercised with a two-step staircase.

The purpose of the present study is, firstly to design a new protocol of a low-level treadmill exercise testing applicable with safety to patients convalescing from acute myocardial infarction, Table 1: Constitutional Parameters of the Forty-Two Healthy Men Studied

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Body weight (kg)</th>
<th>Body height (cm)</th>
<th>Relative weight (%)</th>
<th>Leg length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>24–37</td>
<td>49–81.3</td>
<td>160–180</td>
<td>80.2–117.0</td>
<td>68–80</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>29.8 ± 3.5</td>
<td>64.8 ± 7.9</td>
<td>170.6 ± 5.8</td>
<td>101.3 ± 10.7</td>
<td>73.8 ± 2.8</td>
</tr>
</tbody>
</table>

The relative body weight was the percentage of the actually measured to the standard (body height-corrected) body weight. The correction formula is standard body weight = (body height - 100) × 0.9

1) Treadmill Exercise

Fig. 1. Study design of treadmill and two-step exercise protocols.

In pannel 1) the protocol of a low-level continuous multistage treadmill exercise is shown, and in pannel 2) that of an intermittent two-step exercise is shown. In pannel 2) the asterisk indicates Master's original staircase having a step of 22.9 cm in height.
TABLE II OXYGEN UPTAKE AND THE CIRCULATORY RESPONSE IN THE LOW-LEVEL TREADMILL EXERCISE IN FORTY-TWO HEALTHY MEN STUDIED

<table>
<thead>
<tr>
<th></th>
<th>Rest supine</th>
<th>1.0mph 0%</th>
<th>1.0mph 10%</th>
<th>1.3mph 10%</th>
<th>1.7mph 10%</th>
<th>2.5mph 12%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V\dot{O}_2$ (ml/kg·min)</td>
<td>3.88±0.60</td>
<td>9.03±1.32</td>
<td>11.56±1.32</td>
<td>13.31±1.68</td>
<td>15.82±2.21</td>
<td>21.80±3.29</td>
</tr>
<tr>
<td>MET</td>
<td>1.10±0.18</td>
<td>2.62±0.39</td>
<td>3.32±0.45</td>
<td>3.79±0.48</td>
<td>4.53±0.64</td>
<td>6.23±0.94</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>70.6±8.3</td>
<td>85.0±8.90</td>
<td>91.6±9.50</td>
<td>96.5±10.0</td>
<td>102.8±10.3</td>
<td>116.7±10.9</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>116.4±9.3</td>
<td>124.1±13.1</td>
<td>126.9±14.3</td>
<td>129.4±14.3</td>
<td>133.5±15.8</td>
<td>142.6±18.2</td>
</tr>
<tr>
<td>PRP ($\times 10^3$)</td>
<td>82.2±13.2</td>
<td>106.0±17.6</td>
<td>116.9±21.7</td>
<td>125.3±22.1</td>
<td>137.9±26.3</td>
<td>167.1±31.1</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD.
$V\dot{O}_2$ = oxygen uptake, HR = heart rate, SBP = systolic blood pressure, PRP = pressure-rate product

![Graph](image)

Fig. 2. Correlation between estimated and observed $V\dot{O}_2$ in the low-level treadmill exercise.

The $V\dot{O}_2$ estimated from the equation 3 in the text is plotted on the ordinate against the one actually measured in the low-level treadmill exercise on the abscissa. There was a significant correlation with $\text{SEE} = 2.13$ ($r = 0.90, p < 0.001$). Scattering around the line of identity became wider as the exercise intensity increased.

![Graph](image)

Fig. 3. Linear correlation of heart rate with $V\dot{O}_2$ in the low-level treadmill exercise.

The heart rate (HR) significantly correlated with $V\dot{O}_2$ in the low-level treadmill exercise ($r = 0.70, p < 0.001$). The regression equation was $HR = 68.3 + 2.11 V\dot{O}_2$, with $\text{SEE} = 10.5$. Note the excellent similarity of the above equation to the one for the two-step exercise shown in Fig. 5.

and secondly to know the two-step exercise equivalent in oxygen uptake to a treadmill exercise.

MATERIAL AND METHODS

The whole material consisted of 42 apparently healthy men free from coronary risk factors, whose ages ranged from 24 to 37 with an average age of 30. The constitutional parameters of the material are summarized in Table I. All 42 subjects performed a low-level, continuous treadmill exercise consisting of 5 stages as shown in the upper pannel of Fig. 1. A motor-driven treadmill, Quinton Model 1849-C, was used in the present study.

Two-step exercise was conducted with a metronome used as a pace setter on different days. The initial 12 men performed the first 6 stages of the intermittent two-step exercise.
TABLE III  OXYGEN UPTAKE AND THE CIRCULATORY RESPONSE IN TWO-STEP EXERCISE ON A MASTER'S ORIGINAL STAIRCASE IN FORTY-TWO HEALTHY MEN STUDIED

<table>
<thead>
<tr>
<th>Supine rest</th>
<th>Number of trips*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>$V_o_2$ (ml/kg·min)</td>
<td>3.96±0.67</td>
</tr>
<tr>
<td>MET</td>
<td>1.13±0.20</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>68.9±7.8</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>115.8±9.1</td>
</tr>
<tr>
<td>PRP (x 10^2)</td>
<td>80.1±13.5</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD.
Both SBP and PRP are the values obtained immediately after exercise in the supine position.
*Number of trips per 3 min. Abbreviations are the same as in Table II.

TABLE IV  OXYGEN UPTAKE AND THE CIRCULATORY RESPONSE IN TWO-STEP EXERCISE ON THREE DIFFERENT STAIRCASES AT THIRTY TRIPS PER THREE MINUTES IN THIRTY HEALTHY MEN

<table>
<thead>
<tr>
<th>Height of step</th>
<th>15 cm</th>
<th>19 cm</th>
<th>22.9 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_o_2$ (ml/kg·min)</td>
<td>13.92±1.48</td>
<td>15.97±1.52</td>
<td>18.47±1.70</td>
</tr>
<tr>
<td>MET</td>
<td>3.97±0.43</td>
<td>4.56±0.43</td>
<td>5.25±0.52</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>103.2±9.3</td>
<td>106.3±9.1</td>
<td>107.6±8.2</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>129.1±8.3</td>
<td>128.5±9.6</td>
<td>133.3±9.4</td>
</tr>
<tr>
<td>PRP (x 10^2)</td>
<td>105.1±11.8</td>
<td>106.5±15.8</td>
<td>108.6±13.8</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD.
SBP and PRP are the values obtained immediately after exercise in the supine position.
Abbreviations are the same as in Table II.

shown in the lower panel of Fig. 1. In these 6 stages Master’s original two-step staircase, the step of which was 22.9 cm in height, was employed with a progressive increase in the number of trips from 10 to 60 per 3 min. The subsequent 30 men completed all the 8 stages of the intermittent two-step exercise. In the last 2 stages lower two-step staircases were employed at 30 trips in 3 min as shown in Fig. 1. One of them had a step of 15 cm in height, and the other a step of 19 cm in height. Eleven of the 42 men exercised on the 3 different two-step staircases at 20, 30 and 40 trips in 3 min.

Taking food and smoking were prohibited more than 2 hours before exercise testing. Oxygen uptake ($V_o_2$) was measured continuously using an Electrometabolar, BMS-600, Fukuda-Irika Co. Measurement of blood pressure was made by auscultation syphynomanometrically with the cuff around the left brachium at one-minute intervals during continuous treadmill exercise and immediately after each stage of the intermittent two-step exercise in the supine position. Electrocardiogram (ECG) was continuously monitored on an oscilloscopic screen and recorded on a direct writer at 30-sec or one-minute intervals. Exercise was preformed in a well air-conditioned laboratory.

The duration of a stage was 3 min in both treadmill and two-step exercise as in almost all multistage exercise protocols in current clinical use. The $V_o_2$ during the third minute and the last measurements of heart rate and blood pressure in a stage were considered as the energy cost and the circulatory response in that stage. Parameters such as $V_o_2$, heart rate and systolic blood pressure nearly attained to the steady state in 2 to 3 min after a sudden stepwise

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Fig.4. Correlation of $\dot{V}O_2$ with the number of trips per minute and the height of the step in two-step exercise.

$\dot{V}O_2$ significantly correlated with the number of trips per minute ($f$) in two-step exercise on a Master original staircase ($r = 0.96$, $p < 0.001$) (left panel). It also showed a significant linear correlation with the height of the step when the number of trips was 30 per 3 min ($r = 0.76$, $p < 0.001$) (right panel).

increase in work load in normal subjects.

In the previous study$^1$ the authors derived the following equation for estimation of $\dot{V}O_2$ in treadmill exercise:

$$\dot{V}O_2 \text{ (ml/kg-min)} = d_0 + d_1 v^2 + d_2 v \cdot G \ldots (1)$$

where $d_n$ are partial correlation coefficients, and $v$ and $G$ represent the belt speed and the slope (%) of the motor-driven treadmill, respectively. In the present study the coefficients were calculated using the least square method in the data of the low-level multistage treadmill exercise shown in Fig. 1.

The energy expenditure of two-step exercise is mainly determined by the height of the step (h), the number of trips per minute over the two-step staircase ($f$) and the body weight. In the present study the authors adopted the following equation as a $\dot{V}O_2$ estimator in two-step exercise:

$$\dot{V}O_2 \text{ (ml/kg-min)} = a_0 + a_1 h \cdot f \ldots \ldots \ldots \ldots (2)$$

and $a_n$ were calculated using the least square method.

RESULTS

Low-level Treadmill Exercise

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TABLE V A NEW PROTOCOL OF LOW-LEVEL AND SMALL-INCREMENT TREADMILL EXERCISE TESTING WITH OXYGEN UPTAKE-EQUIVALENT TWO-STEP EXERCISES

<table>
<thead>
<tr>
<th>Energy Cost (MET)</th>
<th>Treadmill Exercise</th>
<th>Two-Step Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>speed (mph)</td>
<td>grade (%)</td>
</tr>
<tr>
<td>2.5</td>
<td>1.0 (1.6)</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1.0 (1.6)</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>1.0 (2.4)</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>2.0 (3.2)</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>2.5 (4.0)</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>2.5 (4.0)</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>2.8 (4.5)</td>
<td>16</td>
</tr>
</tbody>
</table>

Numbers in parentheses represent the belt speed expressed in kilometers per hour. Those under two-step exercise indicate the number of trips per 3 min, which were determined with equation 5 for Master's staircase and with equation 7 for the two lower ones.

Table II shows the mean and standard deviation of measurements obtained in the low-level treadmill exercise performed on all 42 healthy men.

The following equation for $\dot{V}O_2$ estimation in the treadmill exercise was obtained with multiple regression analysis:

\[
\dot{V}O_2 (\text{ml/kg.min}) = 8.29 + 0.98v^2 + 0.25v \cdot G \quad \ldots \ldots (3)
\]

where \(v\) represents the belt speed in mph and \(G\) the slope in percent. The multiple regression coefficient was 0.90 (p < 0.001), and the standard error of estimate (SEE) 2.13 (ml/kg-min). Figure 2 shows the relation between $\dot{V}O_2$ estimated from the above equation (abscissa) and that observed (ordinate).

The heart rate significantly correlated with $\dot{V}O_2$ (\(r = 0.70, p < 0.001\)) (Fig. 3). The regression equation was

\[
\text{HR (beats/min)} = 68.3 + 2.11 \dot{V}O_2 \quad \ldots \ldots (4)
\]

and SEE was 10.5.

Two-step Exercise

All 42 men completed the first 6 stages of the intermittent two-step exercise on a Master's original staircase. The results are summarized in Table III. The $\dot{V}O_2$ correlated significantly with \(f\), the number of trips per minute (\(r = 0.96, p < 0.001\)). The linear regression equation was

\[
\dot{V}O_2 (\text{ml/kg.min}) = 6.85 + 1.17f. \quad \ldots \ldots (5)
\]

with SEE = 1.84 (Fig. 4).

The relation between $\dot{V}O_2$ and the height of the step (h cm) was also analyzed in the data from the 30 men who completed the whole 8 stages of the two-step exercise shown in Fig. 1. The data consisted of $\dot{V}O_2$ of two-step exercise on the 3 different staircases at 30 trips in 3 min (Table IV). There was a significant linear correlation between these 2 parameters (\(r = 0.76, p < 0.001\)) (Fig. 4). The regression equation was

\[
\dot{V}O_2 (\text{ml/kg.min}) = 5.21 + 0.58h \quad \ldots \ldots (6)
\]

The relation of $\dot{V}O_2$ to the number of trips per minute (\(f\)) and the height of the step (h) was also analyzed in the data from the 11 men who exercised on the 3 two-step staircases at 3 different number of trips per minute. Regression analysis gave

\[
\dot{V}O_2 (\text{ml/kg.min}) = 6.10 + 0.05f \cdot h \quad \ldots \ldots (7)
\]

The correlation coefficient was highly significant (\(r = 0.90, p < 0.001\)), with SEE of 1.47.

The heart rate (HR) showed a significant correlation with $\dot{V}O_2$ in two-step exercise (\(r = 0.84, p < 0.001\)) as in treadmill one. The regression equation (Fig. 5) was

\[
\text{HR (beats/min)} = 63.1 + 2.53 \dot{V}O_2 \quad \ldots \ldots (8)
\]

A New Protocol of Treadmill Exercise Testing

Table V shows a protocol of low-level and small-increment multistage treadmill exercise testing designed in the present study. The energy

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expenditure was 2.5 METs in the first stage and 3 METs in the second one, and subsequently, its increment was one MET between the 2 consecutive stages. Since the treadmill exercise in the present study did not exceed 7 METs, the speed and slope of the 7- and 8-MET treadmill exercises in the table were determined from the previous $V_o_2$ formula\(^1\) for modified Bruce protocol of treadmill exercise testing, which approximately covered the exercise of 5 to 13 METs in energy expenditure. The formula was $V_{O_2} = 6.77 + 1.31v^2 + 0.24v. G$. In Table V a treadmill exercise of 2.5-mph speed and 16-percent slope was entered in the 7-MET cell. The estimated $V_{O_2}$ of that exercise is 7.07 METs from the previous formula and 6.98 METs from the present one. The treadmill exercise in the 8-MET cell is 2.8 mph in speed and 16% in slope. The estimated $V_{O_2}$ is just 8.00 METs from the previous formula and 7.76 METs from the present one.

Table V also contains the number of trips per 3 min of two-step exercise, the energy cost of which corresponds to that of the treadmill exercise. The number of trips per 3 min listed under Master's original staircase was determined from equation 5 and that for the cells under 2 other lower staircases from equation 7.

**DISCUSSION**

**Rehabilitative Two-step Exercise**

In-exercise measurement of blood pressure is a prerequisite to modern exercise testing, and its importance has been emphasized repeatedly from the point of view of safety as well as diagnostic importance.\(^2\)\(^-\)\(^6\) Thus, usage of a two-step staircase for exercise testing is severely hampered since blood pressure measurement is practically infeasible during two-step exercise. However, its inherent simplicity and inexpensiveness are a quite attractive nature for rehabilitative exercise of mild to moderate levels of intensity. Rehabilitative exercise has been actually conducted using a Master's two-step staircases? Thus, the authors intended to develop a cardiac rehabilitation system in which exercise prescription was made with a low-level treadmill exercise testing, and actual rehabilitative exercise was conducted using a two-step staircase. Table V shown in the text could facilitate conversion between treadmill and two-step exercise. Measurement of blood pressure was not made during two-step exercise in the present study. On the basis of comparison of blood pressure measured immediately after exercise\(^8\) the authors consider that the blood pressure response is slightly higher during two-step exercise than treadmill one. However, the difference in the blood pressure response seems to be not so large as to require modification of exercise prescription made with treadmill exercise testing.

In two-step exercise, unlike treadmill walk, maintenance of the preset level of the intensity is not under the control of the examiner and depends mainly upon the co-operation of the examinee. This fact is also one of major disadvantages of two-step exercise. The present study showed that $V_{O_2}$ highly significantly correlated with heart rate both in treadmill and two-step exercises and that these two modalities of dynamic leg exercise induced a nearly identical heart rate response when the energy cost was the same. These observations are consistent with our previous preliminary results obtained from a small number of healthy men\(^8\) indicating that continuous monitoring of heart rate with ECG can be a simple, effective means of monitoring the intensity of two-step exercise.

Turning at the end of each trip may be another disadvantage of two-step exercise when the number of trips per unit time is larger. Trips over a series of 2 two-step staircases may alleviate this limitation by reducing the frequency of the turns to the half.

Master's original staircase, which has a step of 22.9 cm height, seems often inadequately higher to the aged in our country. Thus, the authors also studied two-step exercise on 2 lower staircases having 15 and 19 cm step height. The step height of hospital stairways is approximately 15 cm in our country.

**Low-level Treadmill Exercise Testing**

The authors have been using modified Bruce's protocol for diagnostic treadmill exercise testing, which has 2 additional stages below Bruce's original first stage and one more intermediate stage inserted between the original stages III and IV. However, even this modified protocol seems inadequate to evaluate exercise tolerance and to make exercise prescription in patients convalescing from acute myocardial infarction, since the increment of $V_{O_2}$ from a stage to the next is relatively large. In the present study a new protocol of a low-level and small-increment treadmill exercise testing was developed, in which the energy expenditure was 2.5 METs in the first stage and 3 METs in the second one with the increment being 1 MET between the subse-
quent 2 neighbouring stages. In the first exercise testing for patients in the convalescent phase of acute myocardial infarction the new protocol is employed with no abbreviation of stages. In the subsequent tests patients may begin with a higher stage and/or skip one or two stages according to their exercise tolerance capacity.

Naughton\(^9\) developed a multistage protocol of treadmill exercise testing which increased in energy cost by 1 MET by increasing the slope with the speed fixed at 2 or 3 mph. The belt speed of his protocol seems to be too fast for some patients in the early convalescent phase.

\(\dot{V}_\text{O}_2\) in Treadmill Exercise

In the previous study\(^1\) the authors obtained the following estimation equation for \(\dot{V}_\text{O}_2\) in multistage treadmill exercise of higher intensity in a different study group of healthy men: \(\dot{V}_\text{O}_2\) (ml/kg·min) = 6.77 + 1.31\(v^2\) + 0.25\(v\)·G. This equation is similar, as to partial regression coefficients, to that of the present study. This finding seems to provide support for the validity of the estimation equation.

\(\dot{V}_\text{O}_2\) in Two-step Exercise

In the present study a highly significant correlation (\(r = 0.95, p < 0.001\)) was observed between \(\dot{V}_\text{O}_2\) and the number of trips (f) per minute in two-step exercise on a Master's original staircase in a relatively large number of healthy men. The regression equation was \(\dot{V}_\text{O}_2\) (ml/kg·min) = 6.88 + 1.17f, which was quite similar to the one (\(\dot{V}_\text{O}_2 = 5.4 + 1.26f\)) previously obtained from a different study group of 10 healthy men\(^8\).

Nagle et al\(^10\) have shown that the total energy cost in one-step exercise was the sum of the constituent part of the exercise which consisted of standing, stepping horizontally forward, stepping vertically upward, and stepping down. The energy cost of exercising on a one-step apparatus was reported to be determined from the following formula\(^11\): \(\dot{V}_\text{O}_2\) (ml/kg·min) = 1.33 × 1.8f·h + ks, where f was the number of vertical lift per minute, h the height of the step in meter, and ks a constant equal to the energy expenditure requirement for horizontal forward and backward stepping. In the present study dealing with two-step exercise, a highly signifi-
cant correlation was observed between \(\dot{V}_\text{O}_2\) and both of the number of trips per minute and the height of the step, and the authors obtained an estimation formula, \(\dot{V}_\text{O}_2 = 6.10 + 0.05f·h\). The term kw in Nagle et al's formula is clearly a function of f. Thus, their formula can be re-written as \(\dot{V}_\text{O}_2 = c_0 + c_1f·h + c_2f\), if kw is a linear function of f. The authors calculated \(c_0\) in the above formula with the least square method in the preliminary study, and \(\dot{V}_\text{O}_2 = 6.78 + 0.059f·h - 0.23f\) was obtained with \(r = 0.91\). Since a negative partial regression coefficient is illogical in the above equation, the last term was omitted in the final analysis.

REFERENCES
