THE PHYSIOLOGICAL RESPONSES TO WALKING UPHILL UNDER HOT ENVIRONMENT

BY

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ABSTRACT

A series of human experiments on walking uphill under radiant heat in addition to hot environment were carried out and the safety conditions for walking uphill from the standpoint of physiological response were determined.

Experiments were carried out on three healthy adult males aged 21 years, walking uphill on a motor-driven treadmill with the aim of walking at a speed of 45 m/min, 55 m/min and 65 m/min and with a slope gradient of 0°, 5° and 10°. The load weight used was 30, 40 and 50 percent of the body weight for each combination of speed, gradient and load weight.

The subjects were exposed to a radiant heat of 1.3 cal/cm².min, using 12 exsiccating infrared lamps, with a room temperature of 33°C, a relative humidity of 60% and an airflow of 0.7 m/sec.

The following results were obtained by estimating the physiological response (heart rate, respiration rate, rectal temperature and RMR (relative metabolic rate)) to different degrees of walking conditions during the 10-minute exercise:

1) The work intensity (RMR) of uphill walking with a certain load weight under hot environment can be changed by varying the walking speed and the load weight according to the slope gradient.

2) As there exists a gap between RMR 5 and 6 in parallel with the other physiological responses, it is preferable to keep the walking condition under RMR 6, as viewed from the change of the other walking conditions.

3) The heart rate as an indicator of the work load must be kept below 130 beats/min for a safe uphill walking of under RMR 6.

INTRODUCTION

In walking uphill, many factors, such as the walking speed, slope gradient, load weight, etc. have more general effects on the human body than horizontal walking. Many studies on this problem have been reported1-3 already.

On the other hand, it can be said with a fair degree of certainty that walking under a hot environment affects the human body from the viewpoint of environmental physiology4-7. This is because, when exercise or working in the summer season, the air temperature, radiant heat, airflow, etc., which are the environmental factors, are related reciprocally or synergistically to the human body, besides the factors related to the intensity of work, such as speed, load weight, walking time or gradient, etc.

Therefore, walking uphill under a hot environment affects markedly the respiratory and circulatory system.

The affection develops from muscle fatigue to general fatigue or to heat congestion by the disturbance of the thermal
regulatory system. It brings to hazard life at times. For a safe uphill walking under a hot environment, various labour conditions must be kept within the bounds of physiological responses in the man-environment system.

In Japan, research on the labour conditions under a hot environment was done mainly by the Institute for Science of Labour (Rodō Kagaku Kenkyushō)8–10. But there are few field studies on uphill walking during the hot summer season and the date on the physiological reaction of men are also very scarce. Especially, the studies on the combination effects of gradient, speed and load weight under a hot environment, related to radiant heat, are very rare.

The author carried out a series of human experiments on walking uphill under radiant heat in addition to hot environment and determined the safety conditions of walking uphill from the standpoint of physiological response.

**METHODS**

The experiments were carried out between the latter part of June and the first part of July, 1974, in a climate chamber of the size of 4.9 m×8.2 m×3.6 m (148.6 m³).

1) Thermal condition

In this chamber, the room temperature was controlled at 33°C (±0.5°C), the mean daily maximum air temperature in August in Japan. The relative humidity and airflow were 60% and 0.7 m/sec, respectively, which are the usual capacity of this chamber. Twelve infrared exsiccating lamps (100 volts, 250 watts, 2500°K, wave length of 400 to 5000 nm, peak intensity at 1200 nm) were applied vertically (4 lamps in 3 rows) at the height of 2.6 meters from the floor. As the average value of the total radiant heat at noon in August in Tokyo, the value of 1.3 cal/cm² min was adopted11.

2) Walking conditions

The treadmill used in this study was the motor-driven one, consisting of a fabric belt sliding over a wooden platform. The walking gradient and speed were adjustable and controlled at the range of 0 to 10 degrees and 10 to 450 m/min, respectively. In this study, 3 speeds, 45, 55 and 65 m/min, and 3 degrees of gradient, 0, 5 (8.7%) and 10 (17.6%), were used. Three kinds of load weight, 50, 40 and 50 percent of body weight, were used. The weight was adjusted by the sandbags in the rucksack.

3) Subjects

Subjects were three healthy young men whose physical characteristics are shown in Table 1. Each subject wore a green coloured plastic helmet and long sleeve working clothes to avoid the direct effects of the infrared rays.

4) Items measured

The following items were measured: skin

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Chest girth (cm)</th>
<th>Skinfold Thickness* (mm)</th>
<th>Surface area** (m²)</th>
<th>Basal metabolism (Cal/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>166.8</td>
<td>52.8</td>
<td>80.0</td>
<td>8.0</td>
<td>1.54</td>
<td>56.98</td>
</tr>
<tr>
<td>B</td>
<td>22</td>
<td>166.2</td>
<td>54.8</td>
<td>83.0</td>
<td>7.0</td>
<td>1.56</td>
<td>57.72</td>
</tr>
<tr>
<td>C</td>
<td>22</td>
<td>158.5</td>
<td>54.5</td>
<td>88.5</td>
<td>10.0</td>
<td>1.51</td>
<td>55.87</td>
</tr>
<tr>
<td>Mean</td>
<td>21.3</td>
<td>168.8</td>
<td>54.0</td>
<td>83.8</td>
<td>8.3</td>
<td>1.53</td>
<td>56.85</td>
</tr>
<tr>
<td>S. D.</td>
<td>1.2</td>
<td>4.6</td>
<td>1.1</td>
<td>4.3</td>
<td>1.5</td>
<td>0.03</td>
<td>0.95</td>
</tr>
</tbody>
</table>

*: Measured in the right umbilical area (Skinfold caliper)

**: Surface area=W0.44×H0.693×88.83 (Takahira’s equation)
temperature at 7 points on the body surface, rectal temperature at the point 8 cm from the anus, heart rate, respiration rate and blood pressure (systolic and diastolic). The \( O_2 \) consumption, \( CO_2 \) output, respiratory quotient (RQ), heat production and energy expenditure were calculated by analyzing the expired gas.

The skin temperature and rectal temperature were measured by a thermistor and read every 2 minutes.

The heart rate and respiration rate were recorded continuously on a polygraph (Nihon Koden, Type RM-45). The former was taken by the chest lead of ECG and the latter by the thermistor in the nostril through a pickup connected to the recorder. The expired gas was collected in the Douglas bag continuously throughout the experiment and was analysed by the Breath-analyser (Fukuda Irika, Type B-30). The blood pressure was measured on the left brachial artery with the Riva-Rocci sphygmomanometer by the auscultatory method.

Dry and wet bulb temperature (by Assmann's aspiration psychrometer), globe temperature (by Vernon's globe thermometer) and airflow (by the hot wire anemometer) were measured by the side of the treadmill.

5) Experimental procedure

The experiments were carried out under 27 which were established by the above-mentioned three variable factors (3 speeds \( \times 3 \) slopes \( \times 3 \) load weights) and the subjects were ordered to walk on the treadmill according to the prescribed schedule, as shown in Table 2. The exercise for one object was carried out every 2 or 3 days.

**Results**

1) General tendency

To observe the ordinary changes of each item during walking, the measured values are shown as the mean values in Fig. 2, 3 and 4, that is the gradient, speed and load weight. Moreover, the rectal temperature is shown as the increase in the value, taking the value before the walk as zero for each experiment, since the rectal temperature before walking fluctuates every time.

1) \( O_2 \) Consumption, heat production and energy metabolic rate

The changes according to the walking conditions are shown in Fig. 1. The physiological response under all conditions tended to increase according to the increase of the intensity of the walking condition.

2) Heart rate, respiration rate and rectal temperature

The changes in the walking condition with time in each group are shown in Fig. 2-a and 2-b. The changes in the heart rate

<table>
<thead>
<tr>
<th>Time schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>40°</td>
</tr>
<tr>
<td>Preparation</td>
</tr>
</tbody>
</table>

**Table 2. Experimental procedure**

<table>
<thead>
<tr>
<th>Subject</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope gradient</td>
<td>0°</td>
<td>5°</td>
<td>10°</td>
</tr>
<tr>
<td>1) 45 m/min</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>2) 55 m/min</td>
<td>2</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>3) 65 m/min</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>
and respiration rate show a similar pattern in all cases although there are some level differences by the combination of the experimental factors as the heart rate and respiration rate increase suddenly immediately after the start of walking and soon after that they shift to a linear gradual increase.

The tendency of increase of the physiological responses is most remarkable in the slope gradient, then the one in the speed and the one in the load weight is the least.

Particularly, the increase of the heart rate, respiration rate and rectal temperature by the walking speed was the maximum in the group with a speed of 65 meters compared with the other two groups (speed of 55 and 45 meters, respectively).

After the end of the walk load, the heart rate and respiration rate decreased abruptly at once and returned to nearly the previous value 20 minutes later.

The increase of the rectal temperature shows a linear tendency, though there was some difference in the rate of increase.
Fig. 2-a. Change of heart rate and respiration rate due to three factors of walking uphill conditions.

Fig. 2-b. Change in oxygen consumption and rectal temperature due to three factors of walking uphill conditions.
according to the degree of the walk load and there was sometimes a lag of the beginning of the increase of these values compared with the starting time point of walking.

The tendency of increase of the rectal temperature was influenced most dominantly by the slope gradient, then by the speed factor and the least by the load weight. After the end of the walk load, the rectal temperature increased continuously till 10 minutes and then decreased gradually but did not return to the value just before walking but only to the value at the end of walk load during the 20 minutes of measurement.

(3) Blood pressure

The blood pressure change in each group by time is shown in Fig. 3. The systolic pressure shows a remarkable increase just after the end of the walk, i.e. about 20 minutes after the start, and after that it decreased gradually and returned to the first value after 20 minutes. The diastolic pressure showed scarcely any changes. The tendency of increase in the pulse pressure at just after the walk load was a little greater in the 10° groups and the 50% load groups compared with the other groups of the same category.

2) Relationship between \( \text{O}_2 \) consumption and heart rate, respiration rate and rectal temperature.

The tendency of increase in the heart rate, the respiration rate and the rectal temperature during the 2 minutes from the starting time point was almost linear.
Fig. 4. Comparison of the factors concerning physiological response in the three factors of walking uphill conditions.
It was thought that the regression to time, in this case, was expresses the size of the load. Figure 4 shows the regression line, calculated by the least square method, between the load condition and the physiological response during the 8 minutes of time lapse from the point 2 minutes after the walk load to the end of the walk, *i.e.* 10 minutes after walking.

**DISCUSSION**

1) Walking condition and physiological response

The author considers that the O$_2$ consumption is an index showing the grade of the load. In fact, in Fig. 4 it seems that the tendency of increase of O$_2$ consumption is similar to that of the heart rate, respiration rate and rectal temperature. The greatest factor that affects the human body under such an experimental condition is the slope gradient, then the walking speed and the least is the load weight.

The change in the physiological response with time in the group with a slope gradient of 10°, walking speed of 65 m/min, and a

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**Fig. 5.** Change in the factors concerning the physiological response under walking uphill conditions.
load weight of 50\% has the greatest influence on the human body, in the 5°, 55 m/min and 40\% group the influence is of middle grade and in the 0°, 45 m/min and 30\% group the change is the least, as shown in Fig. 5.

It was observed that the slope gradient, walking speed and load weight act upon the human body not only additively but synthetically and bring about complicated physiological responses.

2) Walking condition and work intensity

In walking uphill or going upstairs, the energy metabolism increases as the walking speed and slope gradient increase\(^2,3\).

Also in this experiment, it can be noticed

Fig. 6. Comparison of RMR under walking uphill conditions.
from Fig. 5 that the difference in the walking condition makes the difference in energy metabolism. It can be considered that factors such as the slope gradient, walking speed and load weight influence the human body collectively in a hot environment.

Therefore, in order to study the influence on the human body under variable walking conditions in a hot environment, it is necessary to find the index of the work intensity, which shows the influence of variable walking conditions according to the same standard.

As the index which shows the work intensity during work or exercise, the energy metabolism or gaseous metabolism is often used\(^{(13,14)}\). Asahi\(^{(23)}\) uses the energy expenditure as the index expressing the result of his experiment of walking uphill under a normal air temperature and without load.

Relative metabolic rate (RMR) is one of the indexes which is generally used in Japan\(^{(15,16)}\).

\[
RMR = \frac{\text{Energy requirement of work}}{\text{Basal metabolism}}
\]

In this experiment RMR is used to show the work intensity under different walking conditions. The results of Asahi's experiment are also shown by RMR by the author. The results of both experiments are shown in Fig. 6.

Considering the combination of the low level factors each of which has little influence on the human body, RMR becomes small and the difference of RMR, owing to the difference of the walking conditions, also becomes small. Which of the combinations of the high level factors, each of which has much influence, shows the large RMR. And the difference of RMR, owing to the different walking conditions shows the increasing tendency.

Comparing with the results of Asahi's experiment of walking uphill under a normal air temperature and without load, all the results of his experiment show high figures. It can be recognized that the hot environment and load weight influence the human body as shown in Fig. 6. Consequently, the different changes in the physiological response, owing to the different walking conditions, such as the heart rate, respiration rate, rectal temperature and blood pressure are considered to be due to the difference in the work intensity which is influenced by all the variable walking conditions.

3) Work intensity and physiological response

It is considered that the hot environment influences much the physiological response in muscular work. As Numajiri\(^{(12)}\) suggested in his report, the air temperature and work

![Fig. 7. Correlation between RMR and factors concerning physiological responses just before load ends.](image-url)
THE PHYSIOLOGICAL RESPONSES TO WALKING UPHILL

intensity influence collectively the heart rate, when a man is exposed to a hot environment for a long time. As Ishizaki et al.\textsuperscript{9}) suggested in their report on the walking experiment using a treadmill, it is the air temperature that influences remarkably the increase of the rectal temperature, respiration rate and the heart rate. They say that the effect varies according to the air temperature, \textit{i.e.} whether it is over or under 50°C. As it is considered that in muscular work, the work intensity of which is high, such as walking in a hot environment in this experiment, the influence on the physiological response is at a high degree.

Concerning the physiological response with different work intensity in walking uphill in a hot environment, the author divided RMR into 9 grades and showed their correlation with the heart rate, respiration rate and rectal temperature just before the load ends in Fig. 7 and Table 3.

The physiological response increases as the work intensity increases. There are differences in the tendency of increase of RMR between the curve of RMR 2~5 and that of RMR 5~10. It seems that the collective effects of the hot environment and work intensity appear at the level of RMR 5 to 6 (as for the rectal temperature at RMR 6 to 7). In order to study closely this tendency of increase, the changes in the heart rate and rectal temperature at RMR 4~7, according to the time lapse, are shown in Fig. 8. Especially the change of the heart rate and the difference of the tendency of increase is remarkably recognized at RMR 5~6.

4) Relation between relative metabolic rate and heart rate

According to Numajiri\textsuperscript{17,18}), in reviewing the many results about RMR and the heart rate he stated that there is a rectilinear relation between the RMR and heart rate in

Table 3. Comparison of walking uphill conditions with degree of RMR

<table>
<thead>
<tr>
<th>RMR</th>
<th>Walking condition</th>
<th>RMR</th>
<th>Walking condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>10°.65 m/min. 50%</td>
<td>7</td>
<td>10°.45 m/min. 40%</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>6</td>
<td>5°.65 m/min. 50%</td>
</tr>
<tr>
<td>11</td>
<td>10°.65 m/min. 40%</td>
<td>5</td>
<td>5°.55 m/min. 40%</td>
</tr>
<tr>
<td>10</td>
<td>10°.65 m/min. 30%</td>
<td>4</td>
<td>5°.45 m/min. 50%</td>
</tr>
<tr>
<td></td>
<td>10°.65 m/min. 50%</td>
<td></td>
<td>5°.45 m/min. 40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5°.45 m/min. 30%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0°.65 m/min. 50%</td>
</tr>
<tr>
<td>9</td>
<td>10°.55 m/min. 40%</td>
<td>3</td>
<td>0°.65 m/min. 40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0°.65 m/min. 30%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0°.55 m/min. 50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0°.55 m/min. 40%</td>
</tr>
<tr>
<td>8</td>
<td>10°.55 m/min. 30%</td>
<td>2</td>
<td>0°.55 m/min. 30%</td>
</tr>
<tr>
<td></td>
<td>10°.45 m/min. 50%</td>
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<td></td>
<td>5°.65 m/min. 50%</td>
<td></td>
<td>0°.45 m/min. 40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0°.45 m/min. 30%</td>
</tr>
</tbody>
</table>
muscular work, there is a rectilinear relation within the range of RMR 1~7. The relation between RMR (within RMR 2~7) and heart rate in this experiment is shown in Fig. 9. There is a positive correlation ($r=0.7219^{**}$) and the regression equation is:

$$Y=0.084x-5.477 \quad x: \text{Heart rate} \quad (**: p<0.01) \quad Y: \text{RMR}$$

According to this equation, the heart rate by each RMR is shown in Table 4.

The relation between RMR and heart rate in Asahi's report and of this experiment is shown in Fig. 10. According to this figure, the regression lines of these two results have the same tendency, so that the relation between RMR and the heart rate when walking uphill in a hot environment has the similar tendency as under a normal air temperature. And it is possible to judge the work intensity from the heart rate.

5) Allowable limit for work intensity in a hot environment
Table 4. Comparison of heart rate with degree of RMR

<table>
<thead>
<tr>
<th>RMR</th>
<th>Heart rate (beats/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>148.0</td>
</tr>
<tr>
<td>6</td>
<td>137.0</td>
</tr>
<tr>
<td>5</td>
<td>124.8</td>
</tr>
<tr>
<td>4</td>
<td>116.5</td>
</tr>
<tr>
<td>3</td>
<td>101.5</td>
</tr>
</tbody>
</table>

Fig. 9. Correlation between heart rate and RMR (RMR=2~7).
**: Significant at 1% level

Miura summarized many data on the allowable limit for work in a hot environment which were reported in the past. According to him, there are two permissible standards. One is determining the environmental conditions and the possible exposure time and the other the tolerable limit of some physiological reactions. As for the former, the Japan Association of Industrial Health recommended that it is possible to continue work when it is under the following air temperature.

Light work (under RMR 2)
...up to 34°C (D.B.)

Moderate work (RMR 2~4)
...up to 32°C (D.B.)

Fig. 10. Correlation between heart rate and RMR (RMR=2~7).

Y = 0.084x - 5.021
P < 0.01
r = 0.9402** (Asahi)

Y = 0.084x - 5.477
P < 0.01
r = 0.7219** (Asahi)

Heavy work (over RMR 4)
...up to 30°C (D.B.)

As the latter, Kawai suggests the heart rate as an indicator of the limit of the work load under a hot environment as the heart rate is influenced combinedly by the effects of work load and hot environment. So he recommends to use the heart rate as the limit because it is suitable to show the difficulty of continuing work. Miura proposes the heart rate of 150 beats/min as the limit of the load in a hot environment.

With uphill walking outdoors, it is difficult to apply the measurements which require many instruments. The heart rate is appropriate because it is easy to measure. Therefore, using the heart rate as an index, which shows the permissible level of working in a hot environment, the author set the heart rate limit as 150 beats/min as used generally in the Japanese industries.
from Figs. 7 and 8, the physiological responses, especially the heart rate, increase in different tendencies and their changes according to time are also different. When measured just before the load ends, the heart rate increased to the 120 beats/min level at the work load of RMR 5 and at RMR 6 to the 140 to 150 beats/min level; the heart rate increasing according to the lapse of time is also remarkable at RMR 6 or greater.

If the heart rate of 150 beats per minute

![Graphs showing heart rate, respiration rate, and rectal temperature changes during exercise and recovery.](image)

Fig. 11. Change in factors concerning physiological response due to walking conditions corresponding to the degree of RMR.
is taken as the allowable limit for walking uphill in a hot environment, the work intensity of over RMR 6, which makes, during the 10 minutes of walking uphill, the heart rate increase close to or over the allowable limit, this working condition should be regarded as an exceedingly heavy one. Therefore, it is desirable to have the walking condition under RMR 5. There exists a noticeable gap in the heart rate increase with time between RMR 5 and 6, as shown in Fig. 11.

(2) Walking speed and load weight as seen from RMR

In this experiment, there are 3 factors of variable conditions, each having 3 levels. But, actually in walking uphill in a hot environment, the slope gradient is fixed while the walking speed and the load weight are variable. Further, when walking with a load, the speed is the only factor that can be varied freely. Thus, as in the results of Asahi\(^2\) and those of these experiments (with a load weight of 30 to 50% of the body weight), Fig. 12 shows the RMR by 4 walking speeds, 3 slope gradients and 3 load weight levels, calculated by the least squares method. In every slope gradient group the RMR increases linearly according to the increase of the walking speed, as shown in Fig. 12, and the regression equation of these lines is shown in Table 5. From these data, it can be guessed that the following walking speed would be suitable for RMR 6.

A) In the case of walking with a slope gradient of 10° and a load weight of 30 to 50% of the body weight, it is important that, in order to continue walking for a long time, either the load weight should be lightened or the single walking time should be shortened with repeated rest as well as the walking speed should be under 35 m/min.

B) In the case of walking with a slope gradient of 5°, the walking speed should be under 55 m/min., in order to continue walking for a long time.
Table 5. Correlation between RMR and walking uphill conditions
(Regression equations)

<table>
<thead>
<tr>
<th>Slope gradient</th>
<th>Load weight</th>
<th>N</th>
<th>r</th>
<th>Y = Ax + B</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°</td>
<td>30%</td>
<td>9</td>
<td>0.9248**</td>
<td>Y = 0.166x - 0.244</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>9</td>
<td>0.8690**</td>
<td>Y = 0.177x - 0.389</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>9</td>
<td>0.9285**</td>
<td>Y = 0.238x - 2.246</td>
</tr>
<tr>
<td></td>
<td>Without</td>
<td>12</td>
<td>0.9641**</td>
<td>Y = 0.096x + 0.309</td>
</tr>
<tr>
<td>5°</td>
<td>30%</td>
<td>9</td>
<td>0.8548**</td>
<td>Y = 0.105x - 0.403</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>9</td>
<td>0.8334**</td>
<td>Y = 0.106x - 0.152</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>9</td>
<td>0.9296**</td>
<td>Y = 0.179x - 3.239</td>
</tr>
<tr>
<td></td>
<td>Without</td>
<td>12</td>
<td>0.8838**</td>
<td>Y = 0.040x + 1.080</td>
</tr>
<tr>
<td>0°</td>
<td>30%</td>
<td>9</td>
<td>0.7451*</td>
<td>Y = 0.074x - 1.035</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>9</td>
<td>0.5688</td>
<td>Y = 0.045x + 0.675</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>9</td>
<td>0.8276**</td>
<td>Y = 0.105x - 2.030</td>
</tr>
<tr>
<td></td>
<td>Without</td>
<td>12</td>
<td>0.4334</td>
<td>Y = 0.011x + 1.288</td>
</tr>
</tbody>
</table>

** : Significant at 1% level  
* : Significant at 5% level

According to many of the reports, a load weight under 40% of the body weight is preferable for a long distance walking. It can be said, however, that a load of such weight differs according to the method of bearing load, for example a rucksack may press the thorax and may influence the walking efficiency. In any case, however, as shown in Fig. 12, regardless of the slope gradient, in the 50% load weight group a remarkable increase of RMR is seen compared with 30% or 40% weight loading group in every slope gradient, and it signifies that a load weight under 40% of the body weight has less influence on the human body than that of 50% of the body weight.

Judging from the aforementioned results, with reference to walking with some load weight in a hot environment, it is necessary to choose an appropriate walking speed according to the slope gradient and the load weight for a safe uphill walking.

In the case of walking time, the walking speed should be so determined that the heart rate be under 130 beats/min after 10 minutes walking.

**Conclusion**

The following conclusions are drawn as to the safe walking uphill conditions under radiant heat in addition to hot environment, and applying the physiological responses as the indicators of 3 factors for walking conditions, i.e. slope gradient, walking speed and load weight, each having three degrees:

1) In the case of walking with a certain load weight under a hot environment, the work intensity can be controlled by varying the walking speed and/or the load weight at a certain slope gradient.

2) From the changes of the physiological responses seen from the relation between each walking condition and the RMR, the intensity of the walking load must be under RMR 6.

3) When reckoning the allowable limit for work in a hot environment in terms of heart rate, judging from the relation between the RMR and heart rate, the heart rate under 130 beats/min as an indicator of the walking load is preferable.
4) As to walking with a load under a hot environment, the walking conditions, with regard to the walking speed, the following conditions are preferable, judging from their relation to the RMR:

A) When the slope gradient is over 10°, the walking speed should be under 35 m/min, the load weight under 30% of the body weight and the walk for a short time.

B) When the slope gradient is 5°, the walking speed should be under 55 m/min for every grade of load weight.

5) With regard to the walking conditions from the load weight judging from its relation to the RMR, the influence of walking with a certain weight of under 40% of the body weight is smaller than that with a load weight of 50% of the body weight. But walking with a 50% body weight load influences the RMR remarkably when the walking speed increases.

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