Health promotion with stair exercise

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Received: April 2, 2014 / Accepted: April 14, 2014

Abstract For developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in healthy adults, a minimum of 30 min of moderate-intensity physical activity or 20 min of vigorous-intensity physical activity per exercise day is recommended. However, many adults are still physically inactive because of the lack of time and facilities, bad weather, and other factors. Therefore, it is important to develop a type of exercise that is effective for health promotion and easy to do in daily life. An exercise with stairs is likely to satisfy this aim. Using data from previous studies, we produced the following formula to predict the intensity (oxygen consumption) during stair-ascending exercise. Oxygen consumption (ml/kg/min) = 2.03 x [moving speed for vertical direction in m/min] + 3.7. Previous intervention studies of exercise using stairs show that stair-ascending exercise improves fitness and health, but is too intense for unfit and/or elderly adults. Stair exercise can be performed more easily if it comprises ascending and descending stairs alternately using a short flight of stairs. Our data suggest that stair-ascending/descending exercise expands the availability of stair exercise for health promotion.

Keywords: metabolic syndrome, diabetes, elderly, independence, falls

Introduction

A higher cardiorespiratory fitness level is an independent factor related to a reduction in the risk of cardiovascular events⁵,2). For developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in healthy adults, the American College of Sports Medicine (ACSM)³ recommends a minimum of 30 min of moderate-intensity physical activity five days per week or 20 min of vigorous-intensity physical activity three days per week. However, more than 20% of adults are still physically inactive in many advanced countries⁴,5).

The lack of time and access to indoor facilities are significant barriers to regular physical activity⁶). Weather conditions such as temperature and precipitation can also negatively affect regular participation in physical activity⁷). Therefore, it is important to develop exercises that are effective in health promotion and that are easy to do in daily life.

This review summarizes the studies that have investigated the effects of stair-ascending exercise. Most studies included exercise performed on stairs between multiple floors with the aim of developing fitness and improving health. We also discuss our studies of the use of stair-ascending/descending exercise on a shorter flight of stairs, which can be done at home and at the office, for health promotion.

Work intensity of stair-ascending exercise

The energy cost for ascending stairs under the condition of a stable metabolism was estimated for the first time by Benedict and Parmenter⁸) in 1928. They measured oxygen consumption in four women who ascended a mountain railway with a long unbroken flight of stairs (522 steps) at 48 steps/min (= 10.1 m/min in the vertical direction), and obtained an average gross oxygen consumption of 1519 ml/min for women of an average body weight of 62 kg. When adjusted for body weight, this was equivalent to an oxygen consumption of 24.5 ml/kg/min while ascending stairs. However, this value is probably too low as a representative oxygen cost for ascending stairs because of the low step rate of 48 steps/min. The net energy cost to lift body weight vertically by walking up stairs, which can be done at home and at the office, for health promotion.

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obtained with the unique wearable respiratory apparatus studied by Benedict and Parmenter.

About 70 years later, Bassett et al.\textsuperscript{11}) reported that oxygen consumption while ascending stairs on an escalator with a 0.203 m step height at 70 steps/min ($\approx$ 14.1 m/min in the vertical direction) was about 30 ml/kg/min. Two studies\textsuperscript{12,13}) with 22 flights of stairs (180 steps in total) showed that oxygen consumption while ascending stairs was 33.5 ml/kg/min at 95 steps/min ($\approx$ 14.3 m/min in the vertical direction) and 35.6 ml/kg/min at 100 steps/min (15.0 m/min in the vertical direction). From these four studies\textsuperscript{8,11-13}), a formula to show the relationship between gross oxygen consumption while ascending stairs and moving speed in the vertical direction while ascending stairs was obtained as follows.

\[
\text{Oxygen consumption (ml/kg/min)} = 2.03 \times \text{[moving speed in the vertical direction in m/min]} + 3.7 (r = 0.932)
\]

**Health promotion with stair-ascending exercise**

*Improvement in cardiorespiratory fitness and blood profile.* Table 1 shows a summary of intervention studies\textsuperscript{14-21}) of stair-ascending exercise (see each article for details). Each study except for the last\textsuperscript{21}) confirmed that stair-ascending exercise improved cardiorespiratory fitness in sedentary young and middle-aged adults.

Murphy et al.\textsuperscript{22}) reported that three short bouts (10 min) of brisk walking accumulated throughout the day are at least as effective as one continuous bout of equal total duration, as recommended by the ACSM\textsuperscript{3}), for reducing cardiovascular risk. Macfarlane et al.\textsuperscript{23}) confirmed that accumulating multiple short bouts of lifestyle activity, of which ~50% were of $\leq$6 min duration, can significantly improve the fitness level in sedentary adults. These two studies show that accumulating several short bouts of lifestyle activity has health benefits. However, a comparison of these two studies with those listed in Table 1 shows that the duration of each bout and the total duration of stair-ascending exercise are shorter, especially in studies\textsuperscript{14,16,20}) performed without instruction about the minimum volume for each bout. It is noteworthy that these interventions suggest that cardiorespiratory fitness and the blood profile can be improved by accumulating bouts of short-duration exercise with stairs.

In Table 1, only the study by Boreham et al.\textsuperscript{17}) showed changes in cardiorespiratory parameters during stair-ascending exercise in the figures contained in the article. In one figure showing the data for the experimental (intervention) group, the heart rate at the beginning and at 60 and 120 s after beginning stair-ascending exercise was about 110, 170, and 183 beats/min (see Fig. 1 in ref. 17), respectively. Oxygen consumption at the same times (see Fig. 2 in ref. 17) was about 11, 27, and 33 ml/kg/min, respectively. The maximum oxygen consumption ($\mathrm{VO}_2\text{max}$) for these subjects was not reported in this study. Taking the level of oxygen consumption and heart rate reported for the stair-ascending exercise, we estimated that the $\mathrm{VO}_2\text{max}$ for the subjects before the intervention was 40 ml/kg/min at most. We speculate that the cardiorespiratory response, which is almost maximal at the end of a stair-ascending exercise bout, might be sufficient to improve cardiorespiratory fitness and blood profile regardless of the short duration of exercise and low total energy consumption.

Benn et al.\textsuperscript{24}) reported that heart rate and systolic blood pressure in healthy elderly men during 3 min of stair ascending on a Stairmaster (a stair-stepping device similar to an escalator) reached 150 beats/min and 270 mmHg, respectively. We note that none of these studies are intervention studies of elderly adults except for the last study\textsuperscript{21}).

![Fig. 1](Changes in heart rate during continuous stair ascending and a bout of stair-ascending/descending exercise in a middle-aged man.)
Table 1. Comparison of exercise protocols and effects in interventions using stair exercise

<table>
<thead>
<tr>
<th>Subject</th>
<th>Exercise bout</th>
<th>Vertical height for a bout</th>
<th>Step rate for ascending</th>
<th>Estimated $\dot{V}O_2$ †</th>
<th>Period of time</th>
<th>Frequency</th>
<th>Exercise contents*</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fardy &amp; Ilmarinen (1975) [14]</td>
<td>M15 middle</td>
<td>15 steps (2.7 m/floor) in minimum</td>
<td>Individual 2.7 m×N (N ≤ 10)</td>
<td>100 steps/min 40.2 ml/kg/min</td>
<td>12 weeks</td>
<td>90 floors/week on average</td>
<td>22.5 floors (60.8 m)</td>
<td>438 steps/90 steps = 3.8 min, 44 kcal</td>
</tr>
<tr>
<td>Ilmarinen et al. (1978) [15]</td>
<td>M19 middle</td>
<td>20 steps (3.5 m/floor) in minimum</td>
<td>Individual 3.5 m×N (N ≤ 30)</td>
<td>Free individual</td>
<td>10 weeks</td>
<td>180 floors/week on average</td>
<td>40 floors (140 m)</td>
<td>800 steps/90 steps = 8.9 min, 101 kcal</td>
</tr>
<tr>
<td>Ilmarinen et al. (1979) [16]</td>
<td>F59 middle</td>
<td>27 steps (4.3 m/floor) in minimum</td>
<td>Individual 4.3 m×N (N ≤ 10)</td>
<td>Free individual</td>
<td>12 weeks or 24 weeks</td>
<td>65 floors/week on average</td>
<td>13 floors (56 m)</td>
<td>351 steps/90 steps = 3.9 min, 40 kcal</td>
</tr>
<tr>
<td>Boreham et al. (2000) [17]</td>
<td>F12 young</td>
<td>199 steps</td>
<td>32.8 m</td>
<td>88 steps/min 33.2 ml/kg/min (2.3 min/bout)</td>
<td>7 weeks</td>
<td>1-6 bouts/day (+1 bout/week), 5 days/week at maximum</td>
<td>2.3 min×6 = 13.8 min 32.8 m×6 = 197 m 140 kcal</td>
<td>Decrease in $\dot{V}O_2$, HR and La at a test ascending, increase in HDL-cho and Total/HDL-ratio</td>
</tr>
<tr>
<td>Boreham et al. (2005) [18]</td>
<td>F8 young</td>
<td>199 steps</td>
<td>32.8 m</td>
<td>90 steps/min 33.8 ml/kg/min (2.3 min/bout)</td>
<td>8 weeks</td>
<td>2-5 bouts/day (+1 bout/2week), 5 days/week</td>
<td>2.3 min×5 = 11.5 min 32.8 m×5 = 164 m 120 kcal</td>
<td>17.1% of increase in VO2 max 7.7% of decrease in LDL-cho</td>
</tr>
<tr>
<td>Kennedy et al. (2007) [19]</td>
<td>M16/F13 middle</td>
<td>145 steps</td>
<td>23.9 m</td>
<td>75 steps/min 28.8 ml/kg/min (2.0 min/bout)</td>
<td>8 weeks</td>
<td>1-4 bouts/day (+1 bout/2week), 5 days/week at minimum</td>
<td>2.0 min×5 = 10 min 23.9 m×3 = 71.7 m 52 kcal</td>
<td>9.4% of increase in predicted $\dot{V}O_2_{\text{max}}$</td>
</tr>
<tr>
<td>Meyer et al. (2010) [20]</td>
<td>M39/ F30 middle</td>
<td>20 steps (3.0 m/floor) in minimum</td>
<td>Individual 3.0 m×N (N ≤ 11)</td>
<td>Free individual</td>
<td>12 weeks</td>
<td>Median 20.6 floors/day</td>
<td>20.6 floors (66 m)</td>
<td>412 steps/90 steps = 4.6 min, 48 kcal</td>
</tr>
<tr>
<td>Bean et al. (2002) [21]</td>
<td>M5/F15 old SPPB ≤ 11</td>
<td>21×2 steps (3.4 m²/floor) (unclear)</td>
<td>Free individual</td>
<td>12 weeks</td>
<td>2 floors (ascent/descent) × 3 sets/day with 2-min of rest between sets, 3 days/week</td>
<td>Within 2 min ×3 6 floors (18 -24 m)</td>
<td>126×2 steps 13 -187 kcal</td>
<td>16.5% of increase in leg press power, 11.7% of increase in stair climb power</td>
</tr>
</tbody>
</table>

†: $\dot{V}O_2$ is predicted by $2.03 \times [\text{moving speed for vertical direction in m/min}] + 3.7$. (see body text)
*A*: When step rate is free, 90 steps/min was used to estimate energy consumption.
¶: Short Physical Performance Battery
listed in Table 1. We do not think that stair-ascending exercise is too intense for elderly adults with a higher fitness level, although exercise programs for elderly adults should be delivered carefully.

It is thought those with a higher cardiorespiratory fitness level because of habitual active aerobic exercise (jogging, cycling, and others) would not derive health benefits from stair-ascending exercise except with an additional load\(^{25}\).

**Neuromuscular fitness.** Bean et al.\(^{21}\) demonstrated that three bouts of stair-ascending/descending exercise (42 steps/bout) per day while wearing a weighted vest produced 17% improvement in leg extension power in elderly adults with mobility limitations as estimated by the Short Physical Performance Battery (SPPB). Loy et al.\(^{26}\) also confirmed that prolonged stair-ascending exercise with an external load on a stair-stepping device similar to an escalator improved leg performance (peak torque of knee extension) in middle-aged sedentary women. The results of these two studies suggest that stair-ascending exercise with an external load of less than 10% of body weight is an alternative to weight training of the lower-extremity muscles. However, the effect of stair-ascending exercise on the neuromuscular fitness level of lower extremities is still limited.

**Stair-ascending/descending exercise**

**Exercise intensity.** The exercise intensity of stair-ascending exercise corresponds to that of jogging at 9.6 km/h\(^{27}\). Thus, we think employing the exercise in daily life is rather difficult for sedentary with moderate fitness and normal elderly individuals. However, stair exercise comprised of alternately ascending and descending phases using a short flight of stairs reduces the overall intensity (oxygen consumption per unit time).

Fig. 1 shows the changes in heart rate for a middle-aged man with a body mass index (BMI) of 22.0 kg/m\(^2\) performing the continuous stair-ascending exercise and stair-ascending/descending exercise performed in our pilot study. Ascending exercise involved 24 flights of stairs with a total of 263 steps (47.5 m in height) and ascending/descending exercise involved 12 sets of exercise on a flight of stairs with 21 steps (3.8 m in height). The step rates were 90 steps/min for ascending for both exercises and 75 steps/min for the descending phase of the ascending/descending exercise. Oxygen consumption was estimated by sampling expired gas 1 min before the end of exercise, and was 33.5 ml/kg/min for ascending exercise and 19.2 ml/kg/min for ascending/descending exercise. These results demonstrate that the intensity of stair exercise can be moderated by inserting a stair-descending phase in the exercise program.

To confirm the relationship between body weight and oxygen consumption, we conducted the following experiment comprising three exercises with 24 subjects (age: 20.5 ± 0.8 yrs, VO\(_2\)max: 47.7 ± 8.3 ml/kg/min, mean ± SD). The subjects performed two kinds of stair-ascending/descending exercise on three flights of stairs with 24 steps (4.2 m in height) and level walking with or without loading weights to adjust the individual’s BMI. The step rates

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**Fig. 2** Changes in blood glucose concentration during sitting and exercise in eight middle-aged men with impaired glucose tolerance. Subjects ingested a test meal (106.5 g carbohydrate, 18 g protein, and 18 g fat; 660 kcal), and then 1) sat on a chair for 120 min (REST); 2) sat for 90 min, performed a brisk walk for about 7.2 min, and then sat until 120 min (WALK); or 3) sat for 90 min, performed 12 sets of stair-ascending/descending exercise at a rate of 80–120 steps/min for about 5.5 min, and then sat until 120 min (STAIR). a and b indicate significant differences (P < 0.05) from REST and WALK, respectively.
were 90 and 110 steps/min for ascending exercise and 75 steps/min for descending exercise for both kinds of stair exercise.

Table 2 shows a comparison of oxygen consumption for the three kinds of exercise performed under different BMI conditions. As mentioned previously, stair-ascending exercise is high intensity. However, the intensity of stair-ascending/descending exercise is considerably lower than that of stair-ascending exercise, and can be adjusted by changing the step rate for the ascending phase. The table also shows that the oxygen cost per unit body weight was almost equal regardless of BMI.

It is recommended that, for those physically able, aerobic exercise should be performed at a higher intensity\textsuperscript{27-30}. According to the regression formula for the relationship between VO\textsubscript{2}max and age by Fleg and Lakatta\textsuperscript{31}, a predicted VO\textsubscript{2}max of healthy 30-year-old men and women corresponds to 43.2 and 33.5 ml/kg/min, respectively; and that these values decrease by 3.9 and 2.5 ml/kg/min per decade. Thus, a VO\textsubscript{2}max for a typical 50-year-old healthy man and woman should be 35.2 and 28.5 ml/kg/min, respectively. Walking is a representative exercise for health promotion\textsuperscript{32}. In the context of these values, the intensity of walking in Table 2 is in the middle of moderate for most normal healthy adults. Meanwhile, stair-ascending/descending exercise should be a type of aerobic exercise suitable to the fitness level of unfit to moderately fit individuals across a wide range of age groups. This idea should help motivate those who are willing to start exercise for a short time at an effective intensity.

Control of blood glucose concentration. Because postprandial hyperglycemia has a higher risk of micro/macrovascular complications than does fasting hyperglycemia\textsuperscript{33,34}, it is important for people with diabetes mellitus (DM) or impaired glucose tolerance (IGT) to control blood glucose concentration after meals. We have been investigating the effects of a bout of stair-ascending/descending exercise on postprandial blood glucose concentration in people with IGT\textsuperscript{35} or DM\textsuperscript{36}.

Fig. 2 shows the changes in blood glucose concentration in eight middle-aged men under different conditions. All started with a test meal and then 1) sat on a chair for 120 min (REST); 2) sat for 90 min, performed a brisk walk for about 7.2 min, and then sat until 120 min (WALK); or 3) sat for 90 min, performed 12 sets of stair-ascending/descending exercise for about 5.5 min, and then sat until 120 min (STAIR). As shown in Fig. 2, the bout of stair-ascending/descending exercise reduced the blood glucose concentration quickly and more effectively than did walking. The stair exercise for 5.5 min reduced the blood glucose concentration by 60 mg/dl (3.3 mmol/l). The ability to reduce blood glucose for the stair exercise was three times that for walking. The effect of a bout of stair-ascending/descending exercise on reducing blood glucose concentration was superior to that of pedaling exercise performed at the same heart rate in older people (average age, 72 years) with DM\textsuperscript{36}.

In the context of the decrease in blood glucose concentration following the STAIR condition, the stair-ascending exercise itself may have corresponded to a supramaximal aerobic exercise for these subjects. Exercise of moderate or much higher intensity activates 5′-adenosine monophosphate-activated protein kinase (AMPK) in the working muscles\textsuperscript{37,38}. Energy production during the stair-ascending phase of STAIR, which depends predominantly on glycolytic metabolism, may have led to the activation of AMPK, which in turn facilitates the transport of glucose into working muscles\textsuperscript{39,40}. We believe that the ability of less than 6 min of stair-ascending/descending exercise to cause a net decrease in blood glucose concentration of 40 mg/dl may motivate sedentary people with DM or IGT to use similar exercise to improve glycemic control at work or at home (see ref. 35 for details).

Effect of stair exercise on bone mineral density. Low bone mineral density is a risk factor for fracture in elderly adults regardless of gender\textsuperscript{41}. Exercise involving a high

<p>| Table 2. Comparison of oxygen consumption during stair-ascending/descending exercise and walking |
|-----------------------------------------------|----------------|
| BMI 21.9 | BMI 25 | BMI 30 | BMI 35 |
| [n = 24] | [n = 24] | [n = 24] | [n = 8] |</p>
<table>
<thead>
<tr>
<th>(ml/kg/min)</th>
<th>(ml/kg/min)</th>
<th>(ml/kg/min)</th>
<th>(ml/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascending/Descending</td>
<td>Mean</td>
<td>18.7</td>
<td>18.8</td>
</tr>
<tr>
<td>SD</td>
<td>1.3</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>(↑ 90 / ↓ 75 steps/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ascending/Descending</td>
<td>Mean</td>
<td>20.7</td>
<td>20.3</td>
</tr>
<tr>
<td>SD</td>
<td>1.7</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>(↑ 110 / ↓ 75 steps/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level walking</td>
<td>Mean</td>
<td>14.2</td>
<td>14.2</td>
</tr>
<tr>
<td>SD</td>
<td>1.8</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>(90 m/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BMI 21.9: exercise without additional weight
BMI 25-35: exercise with additional weights to adjust body weight to 25-35 of BMI
strain rate and high peak force is more effective in inducing bone formation than is a large number of low-force repetitions\(^3\). An epidemiological study by Coupland et al.\(^4\) showed that the frequency of stair ascending as assessed by questionnaire (average 10 flights/day (interquartile range 6.0-15.0), 13 steps/flight) was associated with whole-body and trochanteric bone mineral density. Studies have suggested that stair-ascending exercise involves a higher mechanical stress, which should promote bone formation. Stacoff et al.\(^5\) have shown that the average vertical ground reaction force (GRF) while ascending stairs is nearly equal to that for level walking, and that the GRF for descending stairs is 1.4–1.6 times that of ascending stairs. Therefore, the frequency of ascending stairs in the investigation by Coupland et al. might really reflect the frequency of descending stairs. If this speculation is correct, stair-ascending/descending exercise may contribute to an increase in bone mineral density at the trochanter and femoral neck.

**Promotion of stair use**

Several studies have promoted the use of stair exercise. A review of this topic\(^6\) concluded that point-of-choice prompts such as posters or stair-riser banners in public traffic stations, shopping malls, and office buildings increase the number of people using the stairs, especially in escalator settings. This shows that prompting people to use the stairs can help increase the number of people performing exercise as part of their daily life.

**Conclusions**

Previous studies support the beneficial effects of stair-ascending exercise in improving cardiorespiratory fitness and health. However, the intensity of stair-ascending exercise is too high for unfit and/or older adults. Our data suggest that stair-ascending/descending exercise expands the availability of stair exercise for health promotion. Intervention studies are needed to confirm the suitability of stair exercise for health promotion.

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