Energy cost of stair climbing and descending on the college alumnus questionnaire

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Abstract **Author InformationAuthors** **Article OutlineOutline**

In calculating the physical activity index (PAI) on the college alumnus questionnaire, it is assumed that 8 kcal are expended for every 20 steps climbed. This value is equal to an energy cost of 0.40 kcal·step^{-1}. Since it is assumed that subjects climb and descend an equal number of stairs, the total value reflects the energy cost of stepping up (estimated at 0.30 kcal·step^{-1}) and stepping down(estimated at 0.10 kcal·step^{-1}). However, these values appear to be based on theoretical calculations rather than empirical observation. The purpose of this study was to quantify the energy cost of stair climbing and stair descending by measuring oxygen uptake. Twenty subjects performed continuous stair-climbing and stair-descending on an escalator at a stepping rate of 70 steps·min^{-1}. Heart rate was monitored by telemetry, and oxygen uptake was measured by the Douglas bag technique from 5 to 7 min. Results showed that the gross energy cost of stair climbing is 8.6 METs, and that of stair descending is 2.9 METs. Thus, for a 70-kg person the gross caloric costs of ascending stairs (0.15 kcal·step^{-1}) and descending stairs (0.05 kcal·step^{-1}) are one-half of the values previously assumed. In conclusion, the algorithm for calculating PAI on the college alumnus questionnaire should be modified to reflect a total cost of 0.20 kcal for going up and down one step. Even more precise estimates can be obtained by adjusting for body weight (going up and down one flight of stairs requires 1.63 MET·min).

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Epidemiological studies have demonstrated that there is an inverse relationship between physical activity and risk of cardiovascular disease. The most common method of assessing physical activity in free-living subjects is through the use of questionnaires. These questionnaires typically ask a person about the types of activities that he/she has engaged in over a certain period of time (ranging from 1 wk to 1 yr). The caloric cost of these activities is then estimated from the Compendium of Physical Activities (a listing of the caloric costs of different types of tasks)[2]. The person's average weekly caloric expenditure can thus be approximated.

One of the better known physical activity surveys is the college alumnus questionnaire, designed by Paffenbarger et al.[3,11,12,16,18]. These investigators calculate a physical activity index (PAI) on the basis of distance walked, flights of stairs climbed, and sports and recreational activities. Subjects are asked "How many flights of stairs do you climb*up* each day? (Let 1 flight = 10 steps)"[16]. The assumption is made that if a person climbs several flights of stairs, they descend an equal number of flights. Climbing up and down one step is assumed to be equal to 0.40 kcal·step^{-1} [18]; this figure assumes an energy cost of 0.30 kcal·step^{-1} for ascending stairs, and 0.10 kcal·step^{-1} for descending. If correct, this would mean that stair climbing, even at a slow rate of 70 steps·min^{-1}, would require an oxygen uptake ($\dot{V}O_2$) of 4.20 L·min^{-1}!

Nagle et al. [14] measured the energy cost of stepping up onto a platform (a hand crank or motor was used to lower the subject back to the starting level after each step). They found the net energy cost to be 1.8 mL·kgm^{-1} for stepping up, and about one-third of that for stepping down. When added to the metabolic cost of horizontal stepping, these values correspond to 0.16 kcal·step^{-1} for stepping up and 0.07 kcal·step^{-1} for stepping down (for a 70-kg subject and 8-inch standard step height)-far less than the values assumed by Paffenbarger et al. [18]. In addition, recent studies using the StairMaster 6000 (or "Gauntlet") device also suggest that the actual cost of stair climbing is much lower than the value assumed on the college alumnus questionnaire [4,7,10]. However, the StairMaster device uses the person's body weight to turn the stairs, and a braking mechanism absorbs energy to slow the rate of descent.

To our knowledge, the energy cost of stair descending on a motor-driven escalator has not been measured. The purpose of the present study was to determine the caloric requirements of stair climbing and descending. Subjects performed continuous stair climbing or descending on an escalator until they attained a metabolic steady state. Oxygen uptake and carbon dioxide production were measured during minutes 5 to 7 of the bout, and these data were used to compute the caloric requirements of each activity.

METHODS

Subjects. The subjects in this study were 10 males and 10 females. Data for two females who failed to achieve a metabolic steady state during stair climbing were not used in the analysis. The physical characteristics of the remaining 18 subjects are shown inTable 1. Persons who performed 30 min of exercise three or more times per week were recruited to minimize the risks of exercise and to increase the likelihood that they would be able to attain a metabolic steady state during stair climbing. The nature of the study was explained to the subjects, and they were asked to sign an informed consent form before taking part in the study. Subjects also filled out a physical activity readiness questionnaire (PAR-Q) and were excluded if they had any contraindications to exercise testing.

Maximal exercise testing. The subjects underwent anthropometric testing (height, weight, sum of skinfolds [8]. They then performed a maximal, graded treadmill test to determine peak oxygen uptake($\dot{V}O_{2peak}$) and maximal heart rate (HR_{max}). The test began at a comfortable running speed (ranging from 134 to 255 m·min^{-1}), and the treadmill grade was gradually increased by 2% at 2-min intervals until the subject was unable to continue. Heart rate was monitored by a Polar (Polar Electro, Kempele, Finland) heart watch [9]. Minute ventilation was measured by a calibrated flow meter (Rayfield Equipment, Waitsfield, VT). Percentages of expired oxygen (O_2) and carbon dioxide(CO_2) were measured with Applied Electrochemistry analyzers (Sunnyvale, CA) connected to a computerized system. The analyzers were calibrated using known gases analyzed by the Scholander technique [22]. Oxygen uptake ($\dot{V}O_2$) and carbon dioxide production($\dot{V}CO_2$) were calculated using the Haldane transformation of the Fick equation. Peak oxygen uptake ($\dot{V}O_{2peak}$) was determined from the highest oxygen uptake achieved during the test.

Stair climbing and stair descending. A motorized escalator with a step height of 20.3 cm (8 inches) and rate of 70 steps·min^{-1} was used for the study. Subjects ascended the "down" escalator for a total of 7 min. After allowing 5 min to reach steady state, expired air was collected from minutes 5 to 7. Subjects wore a mouthpiece, Daniels valve, and nose clip, and the expired air was directed into 200-L Douglas bags. Subjects also descended the "up" escalator for 7 min to measure the energy cost of walking down stairs using the same protocol.

The Douglas bags were transported back to the laboratory for analysis. A small sample (300 mL) was removed for gas analysis, and the volume of the remaining air was determined using a 120-L Tissot gasometer. Oxygen uptake and carbon dioxide production were calculated, and the respiratory exchange ratio(RER) was used to convert the oxygen uptake values to kcal·min^{-1} [13]. Subjects were excluded from the analysis if their measured $\dot{V}O_2$ during stair climbing exceeded 80% $\dot{V}O_{2peak}$. Below this intensity, there is only a minor contribution of anaerobic pathways, and the measured oxygen uptake is a close approximation of the total energy expenditure [6].

Data analysis. The descriptive data on the subjects' physical characteristics were tabulated according to gender, and the mean and SD for males and females were computed. Data for the stair climbing and stair descending trials were analyzed separately. Dependent variables for the energy cost study were: $\dot{V}O_2$ (L·min^{-1}), $\dot{V}O_2$(mL·kg^{-1}·min^{-1}),% $\dot{V}O_{2peak}$, respiratory exchange ratio (RER), kcal, METs, and heart rate. Gender differences were analyzed using an unpaired Student's*t*-test. A two-tailed comparison and significance level of$P$ = 0.05 were used throughout.

RESULTS

The stair-climbing data are presented in Table 2. (All values referred to in *Results* and *Discussion* are the"gross" energy costs, unless otherwise stated.) Two female subjects were excluded from the analysis because their $\dot{V}O_2$ during stair climbing exceeded 80% $\dot{V}O_{2peak}$ and their RER values were above 1.00. For the remaining subjects, the energy requirement represented 62% $\dot{V}O_{2peak}$. Males had higher values for energy expenditure when expressed as L·min^{-1} (2.21 ± 0.24 vs 1.81 ± 0.20) or kcal·min^{-1} (10.92 ± 1.22 vs 9.08 ± 1.05)(P < 0.05). However, this difference was a result of a greater body mass in the males. When expressed relative to body mass, no gender difference in energy cost was apparent. The energy cost was 29.9 mL·kg^{-1}·min^{-1} or 8.6 METs for the overall group. This represents an net oxygen cost (exercise $\dot{V}O_2$ minus predicted $\dot{V}O_2$ of horizontal stepping) of 1.71 mL·kgm^{-1} of vertical work.

The stair-descending data are presented in Table 3. As with stair climbing, males had higher values for energy expenditure when expressed as L·min^{-1} (0.76 ± 0.11 vs 0.59 ± 0.05) or kcal·min^{-1} (3.70 ± 0.56 vs 2.86 ± 0.23)(P < 0.05). Once again, when the energy cost was expressed relative to body mass there was no significant difference between males and females. The energy cost was 10.1 mL·kg^{-1}·min^{-1} or 2.88 METs for the overall group. The gross energy cost of descending stairs was one-third that of ascending. However, the net oxygen cost of descending stairs (0.31 mL·kgm^{-1}) was closer to one-sixth of the net cost of ascending.

Subjects attained a steady state in heart rate by 5 min into the exercise bout. The average heart rate during the last 2 min of exercise of stair climbing averaged 142 ± 21 for males and 165 ± 21 beats·min^{-1} for females. During stair descending, average heart rates were 93 ± 20 beats·min^{-1} for males and 103 ± 17 beats·min^{-1} for females.

DISCUSSION

The college alumnus questionnaire is one of the better known surveys used to quantitate physical activity in kcal·wk^{-1} or MET·min·wk^{-1}. It has provided vital information on the dose-response relationship between physical activity and heart disease. Hence, an accurate estimate of the energy costs of physical activities is desirable. The results of the present study indicate that a modification is needed in the scoring of the college alumnus questionnaire. Ascending stairs costs approximately 0.15 kcal·step^{-1} and descending costs 0.05 kcal·step^{-1} for a 70-kg person, for a total cost 0.20 kcal for going up and down one step. If the college alumnus algorithm is modified to use the correct values for the caloric cost of stair-climbing, it would lower the energy expenditure of stair climbing by one-half. This modification would lower the physical activity index (PAI) by only 5-10%, since stair-climbing accounts for a small fraction of the total weekly energy expenditure.

For the college alumnus questionnaire, the energy cost of stair climbing has been variously expressed as 8 kcal for climbing two flights of stairs[18], 28 kcal for climbing 70 stairs[17], and 118 kJ·wk^{-1} for climbing up and down one flight of stairs daily [12]. These values are all equal to 0.40 kcal·step^{-1}. Paffenbarger et al.[17] took the energy cost estimates for stair climbing and other activities from Passmore and Durnin [19]. This source cites three English-language references for stair climbing[5,20,21], which are discussed in the following paragraphs.

Schneider and Karpovich [21], on the basis of theoretical arguments, state that a 70-kg woman would have to go up and down a flight of stairs about 1000 times to burn off a pound of fat. This yields 0.35 kcal·step^{-1}, which is far higher than what we observed. In contrast, Passmore et al. [20] actually measured the average cost of going up and down stairs using a Kofrani-Michaelis calorimeter. Their five subjects expended 6.7 METs at an average vertical speed of 14.8 m·min^{-1}. This is only slightly higher than that observed in our subjects, who expended an average of 5.8 METs (up = 8.56 METs, down = 2.88 METs) for the stair climbing and descending at 14.2 m·min^{-1}. The difference could be a result of the weight of the Kofrani-Michaelis device, differences in step height (15 vs 20 cm), and the faster speed used by Passmore et al. [20].

Benedict and Parmenter [5] measured the $\dot{V}O_2$ of ascending or descending stairs in female college students. They used a unique, portable, closed-circuit system for measuring oxygen uptake that has rarely been described in the literature. In the first experiment subjects climbed up six flights of indoor stairs in a little under 2 min. Subjects performed 3 to 4 min of horizontal walking at 72 steps per minute before climbing the stairs (to decrease the time needed to attain steady state). The authors noted: “To avoid this period of transition in any building other than an American sky-scraper is out of the question. The ideal conditions would be to have the subject climb a long flight of stairs or an escalator and not begin the measurements until the metabolism had reached the climbing level.”

Hence, the second set of experiments was conducted on a long mountain staircase (522 steps) parallel to a mountain railway on Mount Holyoke. The authors concluded that the net energy cost of stair climbing (over and above that of horizontal stepping) is 9.3 cal·kgm^{-1} (equivalent to 1.86 mL·kgm^{-1}), slightly higher than our value of 1.71 mL·kgm^{-1}. They noted that the gross energy cost of descending stairs is one-third that of ascending, while net energy cost of descending is one-fifth that of ascending. These latter findings are also in agreement with the present study.

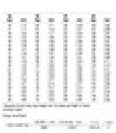
The 1993 Compendium of Physical Activities compiled by Ainsworth et al.[2] lists the gross energy cost of “walking, carrying load upstairs, general” at 9 METs. and the cost of“walking, downstairs” at 3 METs. These values were estimated from the vertical constant for bench stepping (net cost = 1.8 mL·kgm^{-1}) listed in the ACSM Guidelines [1] and from the work of Nagle et al. [14]. Our results are generally consistent with these sources, and they support the use of the vertical constant (1.8 mL·kgm^{-1}) in predicting the energy cost of stair-stepping activities.

Several previous studies have examined the energy cost of stair climbing on the StairMaster 6000 (or “Gauntlet”). This device uses a rotating stair-case (21 cm step height) which is driven by the subject's body weight, and a braking mechanism to slow the rate of descent. The oxygen cost was found to be in the range of 5 to 7 METs at 50 steps·min^{-1}, and 8 to 10 METs at 75 steps·min^{-1} [4,7,10]. In general, these studies have yielded $\dot{V}O_2$ values which are reasonably close to the predicted value obtained when the rate of vertical rise is multiplied by 1.8 mL·kgm^{-1} and added to the cost of horizontal stepping. Once again, our results are in agreement with these studies, and they indicate that the energy cost of stair climbing is lower than previously assumed on the college alumnus questionnaire.

Body weight affects the caloric cost of stair climbing and descending. The average (mean) weights of a U.S. adult male and female from the National Health and Nutrition Examination Survey (NHANES) I and II are 78.1 kg and 65.4 kg, respectively [15]. We assumed a body weight of 70 kg in calculating the caloric cost for an average person, but it should be recognized that the cost is dependent on the assumed value for body weight. In our study, males used more energy (kcal) than females, but this was entirely a result of differences in body weight. Expressing data relative to body weight is preferable since heavier subjects expend more energy in absolute terms during stair climbing. Going up and down one flight of stairs requires 1.63 MET·min regardless of body weight (see calculation at end of article). Based on this figure, we derived gross energy cost estimates (kcal) for individuals of various body weights, and these are listed inTable 4.

In summary, the energy cost of stair climbing was found to be 0.15 kcal·step^{-1} and the cost of stair descending was 0.05 kcal·step^{-1} for a 70-kg person. The college alumnus questionnaire asks only how many steps are climbed *up*, and the implicit assumption is that subjects go *down* an equal number of steps. The correct energy cost estimate for going up and down stairs is taken from the sum of the previous two figures (0.20 kcal·step^{-1}). This is about one-half of the value previously assumed by the college alumnus questionnaire, indicating that a minor modification is needed in scoring the physical activity index (PAI). More precise estimates can be obtained by taking body weight into account.

Note: The number of MET·min expended in going up and down a flight of stairs can be calculated as follows: Ascending a flight of stairs(10 steps) at 70 steps·min^{-1} requires 1/7th of a minute. The rate of energy expenditure for this activity is 8.55 METs regardless of body weight. 8.55 METs × 1/7th of a minute = 1.22 MET·min^{-1}. Descending a flight of stairs at 70 steps·min^{-1} also requires 1/7th of a minute. The rate of energy expenditure for stair descending is 2.88 METs. 2.88 METs × 1/7th of a minute = 0.41 MET·min^{-1}. So, the total amount of energy needed to go up and down a flight of stairs is 1.22+ 0.41 = 1.63 MET·min^{-1}.



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