

Energy Expenditure and Fitness Response Following Once Weekly Hill Climbing at Low Altitude

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Key words

- VO₂max
- resting metabolic rate
- body composition
- physical activity

Abstract

This work sought to determine the fitness responses and energy expenditure (EE) following once-weekly hill climbing for 16 weeks on different slopes. A cohort of 98 healthy, sedentary subjects (49 female, 49 male) completed the program at their preferred climbing pace. Body composition, resting metabolic rate (RMR) and VO₂max were measured. EE was measured on 4 slopes (11.6°, 19.9°, 14.9°, and 28.6°) at the subjects' preferred speed. In males, weight, body mass index, fat mass significantly decreased ($P < 0.05$), and RMR showed an increasing trend, but the difference was not significant ($P = 0.051$). In females, the muscle mass increased significantly, and fat

(%) and fat mass significantly decreased ($P < 0.05$). Absolute and relative of VO₂max, ventilation (VE) improved significantly in both sexes ($P < 0.01$). Energy expenditure was similar on different slopes, but shows gender-specific values of approximately 50.4 and 33.6 kJ/min for males and females, respectively. The regression equation of EE (kJ/min) = $[1.724 \times (\text{female} = 1, \text{and male} = 2) + (-0.072 \times \text{age}) + 0.106 \times \text{weight} + 0.024 \times \text{HR} + 0.136 \times \text{slope} + 1.487 \times \text{velocity}] \times 4.2$. In conclusion, hill climbing at a subjects' preferred velocity is a vigorous-intensity physical activity for energy cost and, performed once weekly, enhances cardiorespiratory fitness and reduces fat mass, therefore making it a viable exercise for most people.

Introduction

The higher prevalence of obesity [12] may reflect the imbalance between energy intake and expenditure, where energy intake exceeds energy expenditure over some period of time. Similarly, weight loss can occur only when energy expenditure is elevated above energy intake for a period of time. Finally, when energy intake is matched to energy expenditure, body weight remains constant [15]. To achieve significant safe weight loss, a minimum energy intake of 5040 kJ/day for women and 6300 kJ/day for men, respectively [38], has been suggested. There is an inverse linear dose-response relationship between volume of physical activity and all-cause mortality, and an energy expenditure of about 4200 kJ/week is associated with a significant 20–30% reduction in risk of all-cause mortality [13]. Approximately 31% (95% CI 30.9–31.2) of adults are physically inactive, with proportions ranging from 17.0% in southeast Asia to about 43% in the Americas and the eastern Mediterranean [16]. Increased physical activity (PA) and exercise training (ET) is therefore recom-

mended for improving energy expenditure [21] and as a component of weight management for prevention of weight gain, for weight loss, and for prevention of weight regain after weight loss [11,49]. Increased PA and ET have been included in 88% of successful weight loss and weight maintenance intervention programs [38]. A negative energy balance generated by PA/ET will result in weight loss, and the larger the negative energy balance, the greater the weight loss [11]. A dose effect is apparent for PA and weight loss, and higher doses are capable of providing 3% or greater weight loss from initial weight [11]. Exercise expenditure > 10500 kJ/week were substantially better at promoting long-term weight loss than that of < 4200 kJ activity/week and 4200–10500 kJ. Specifically, 2.5 years after baseline, participants reporting > 10500 kJ activity/week lost an average of 7 kg from baseline weight, whereas the other 2 groups had average weight losses of < 1 kg [50]. Resting metabolic rate (RMR) accounts for 60–70% of daily energy expenditure and any interventional behavior that chronically alters RMR may have important implications for energy-balanced weight control [47]. Exercise is

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a possible means to increase RMR, which could offset age-related metabolic declines and facilitate weight management [36]. As such, exercisers are intuitively concerned about the calories used when exercising. They would like to know whether a particular physical activity is effective in expending the desired amount of calories. Thus, understanding and accurately assessing the energy expenditure of different types of physical activity is important for exercise prescription and for recommending the dose-dependent physical activity.

While climbing and mountaineering sports are gaining more and more public interest [41], most research concerning the energy cost of mountaineering has focused on high-altitude expeditions (>4000 m) [30], moderate altitude (2500–3800 m) [5] and rock climbing [14]. Low-intensity physical exercise in normobaric hypoxia (15% O₂, ≈2500 m) leads to more weight loss in obese people than low-intensity physical exercise in normobaric sham hypoxia [33]. Very little data are available concerning the physical activity of hill climbing at low altitude. Stairway climbing has been shown to be effective in burning calories [17, 51] and in improving cardiovascular fitness [4]. Single-step stairway climbing used 35.7 kJ/min [17] or 42.84 kJ/min [51] during ascent at speeds chosen by the participants. Relative to controls, the stair-climbing group displayed a 17.1% increase in VO₂max [4], which is regarded as the gold standard in cardiorespiratory fitness assessment [26]. Physical activity plays a critical role in improving cardiovascular health [53] and is generally associated with more favorable cardiovascular biomarker levels than inactivity, and higher levels of cardiorespiratory fitness are associated with a lower risk of developing health problems [13]. There are currently no studies that have investigated the effects of hill climbing on cardiorespiratory fitness and energy expenditure at different slopes.

Overweight and obese individuals as well as persons of average weight often report not having time to exercise [53]. But how much physical activity is a minimum threshold of intensity needed to improve cardiorespiratory fitness [11]? Studies have supported a dose-response relationship between chronic physical activity levels and health outcomes [13], such that greater benefit is associated with higher amounts of physical activity. However, findings are inconsistent. As a result, data regarding the specific quantity and quality of physical activity for the attainment of the health benefits are less clear and need to be further studied.

The purpose of this study was therefore to determine body composition, RMR and cardiorespiratory (VO₂max) responses after hill climbing once a week for 16 weeks at an altitude of 565 m and to measure the EE under different slope angles at the subjects' preferred speed during a hill climbing session.

Method

Subjects

Prior to testing, the subjects were instructed to complete questionnaires about their recreational activities, medical history and physical status. A group of 98 (49 females, 44±10 years, 161.1±5.9 cm, 59.2±8.3 kg, 22.78±2.79 kg/m²; 49 males, 42±11 years, 172.5±5.4 cm, 73.5±10.6 kg, 24.65±3.12 kg/m²) healthy, sedentary subjects were selected. The subjects had no cardiovascular disease, diabetes or abnormal glucose tolerance, or any other acute or chronic disease. In the previous 12 months they undertook no regular physical exercises (less 2 times one week

and each time less than 20 min, or the total time less than 75 min in one week). The experimental protocol was ethically conducted in accordance with international standards and as required by the journal [20] and was approved by the Ethics Committee of the Chinese Institute of Sport Science. Before inclusion in the study, subjects were informed of the objectives and procedures and then provided their written, informed consent. After having their initial measurements taken, the participants were requested to climb a hill at their preferred velocity on a fixed route once a week for 16 weeks. The preferred velocity was the maximum speed that the subject could maintain steadily while continuously climbing. The participants were not permitted to carry out other regular moderate and vigorous physical exercises. There were no injuries over the course of the study. Energy expenditure was measured as climbing was undertaken over a 16-week period at the end of September and in early October. We selected 8 days which had roughly the same pleasant temperature (19±2°C) and atmospheric pressure (978±6 mbar). Among 98 subjects, 77 subjects (40 female, 44±10 years, 161.5±6.3 cm, 58.8±8.7 kg; 37 male, 40±12 years, 172.8±5.1 cm, 72.3±11.4 kg) had time and were willing to participate in the energy expenditure experiments when climbing. One week after the climbing energy expenditure measurements were taken, body composition, RMR, and VO₂max were determined again for the 98 subjects.

Body composition

Anthropometric measurements were taken on the first test session and included, weight and height (Jianmin II, Beijing Xin Dong Hua Teng, Beijing, China), which were measured with the subjects wearing only their underwear. Height was taken to the nearest 0.1 cm using a calibrated stadiometer (Jianmin II, Beijing Xin Dong Hua Teng, Beijing, China), and weight (Jianmin II, Beijing Xin Dong Hua Teng, Beijing, China to the nearest 0.1 kg using an electronic platform scale. Body composition and bone mineral density (BMD) were determined by the whole body dual energy X-ray absorptiometry scan (GE LUNAR DPX system, Madison, WI). Body fat percentage (fat%), fat mass, and muscle mass were reported for different parts, left arm, left leg, left trunk, left whole body, right arm, right leg, right trunk, right whole body, upper whole body, lower whole body and whole body, respectively. Bone mineral density were also reported for different parts, left arm, left leg, left trunk, left whole body, right arm, right leg, right trunk, hip, rib, pelvis, spine and whole body, respectively.

Resting metabolic rate

Resting metabolic rate (RMR) was measured by indirect calorimetry using measurement of VO₂ and VCO₂ (MetaMax 3B, Cortex, Biophysik, Germany) [28]. The MetaMax 3B system analyzer unit was calibrated according to the manufacturer's instructions before each testing session. Early in the morning (7:00 a.m.), the subjects came to the laboratory after an overnight 12-h fast and abstinence from smoking, caffeine and alcohol [8]. Subjects were also required not to have undertaken any vigorous physical activity in the 48 h prior to testing. Each participant was familiarized with the procedures and equipment used for the RMR analysis, and had at least 10 min to rest before the study commenced. The test room was comfortably appointed with minimal light and noise. Ambient room temperature was maintained at ~22±1°C. The subjects were supine in a bed and were monitored periodically to ensure that they remained awake but as

quiet as possible before and throughout the entire RMR session. After the RER was between 0.7 with 0.8, METs was approximately equal to 1.0, and the VO_2 (ml/min/kg) was about 3.5 ml/min/kg, the gas was formally collected for 20 min. A VO_2 variation of <25 ml/min was used to determine whether the collection was acceptable. Testing lasted 20 min, with the first 5 min being disregarded [8]. Energy expenditure was calculated from the mean respiratory gas exchange of the last 15 min according to Weir equation: $\text{EE (kJ/min)} = [3.9 \times \text{VO}_2 \text{ (litres/min)} + 1.1 \times \text{VCO}_2 \text{ (liters/min)}] \times 4.2$ [54].

Maximal oxygen uptake

Maximal oxygen uptake ($\text{VO}_{2\text{max}}$) was measured breath-by-breath (MetaMax 3B, Cortex, Biophysik, Germany). After being provided with instructions on how to use the bicycle ergometer (Ergoselect 100, Ergoline, Germany), subjects performed a brief 5-min warm-up at 20 W. The technicians explained to each subject the rating of perceived exertion (RPE) (Borg 1974) and rating of perceived breathlessness (RPB) according to the Borg scale of 6–20 and 0–10, respectively, and then instructed him or her how to show the values during the measurement process. Maximal oxygen uptake was determined by the following continuous incremental intensity protocol. The initial intensity on the bicycle ergometer was 25 W and 20 W at 60 rpm for men and women, respectively and was increased by 25 W or 20 W every 2 min until volitional exhaustion. RPE and RPB were recorded at the end of the 2-min load by having the subject point to a printed chart. The test was deemed to be a valid maximal test if at least 3 of the following criteria were met during the last completed stage [22]: a plateau in VO_2 despite increasing exercise intensity; subject was no longer able to maintain the required intensity; a respiratory exchange ratio exceeding 1.10; achievement of age-predicted HR_{max} and a rating of perceived exertion of 20. Breath-by-breath data for ventilation (VE), oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER) were averaged over 10-s intervals and exported to an Excel spreadsheet prior to analysis. Heart rate was recorded via a chest strap transmitter (polar RS400, Polar Electro, Kempele, Finland), which was coded for the expired air analyzer telemetry receiver. The HR data was entered into the analyzer data file along with the breath-by-breath expired air analysis data and were averaged over 10-s intervals for final data analysis. The HR data were filtered through visual editing to eliminate undesirable noise or premature beats.

Energy expenditure when climbing

Energy expenditures at different slopes were determined with a portable gas analysis system (MetaMax 3B, Cortex, Biophysik, Germany). The hill has a peak altitude of 565 m, and participants climbed a specific route to the summit of the hill once a week (total distance = 2.43 km) (see Fig. 1), with total climb time being recorded each time. After 16 weeks, we measured the energy expenditure of climbing at 4 different slope angles. Subjects were instructed on the test procedures, and performed the climbing at least 2 h post-prandial to reduce the influence from the thermic effect of food on overall energy expenditure [35].

We selected 2 parts of the climbing route to measure the energy expenditure of hill climbing (see Fig. 1). The first part has a relatively stable slope, while the second part has steps as well as 3 relatively stable slopes. 5 markers were placed (see Fig. 1) along the route, with marker 1 being the starting point located 1.16 km from the park gate. The subjects climbed to the marker 1 from the gate at their usual speed and then rested for 20 min. During this time the MetaMax 3B system was attached to the subjects, as was the heart rate monitor (Polar RS800, Polar Electro, Kempele, Finland). Marker 2 was the end of the first part of the route. At marker 2, expired air data were recorded continuously during a 20-min sitting recovery period immediately after climbing. The 20-min recovery period was selected to provide an assessment of most of the excess post-exercise oxygen consumption (EPOC). Following the 20-min recovery, participants were allowed to breathe without the facemask and drink water, but were not allowed to eat food or drink any calorie-containing beverages for several minutes. Marker 2 was also the start point of the second part of the route. The distance between marker 2 and marker 3 is the second slope, marker 3 and marker 4 the third slope, and marker 4 and marker 5 the fourth slope. Marker 5 is the end of the second part, at which point 20-min sitting recovery expired air data were also collected.

Subjects were requested to climb at a brisk, rhythmic and constant velocity at their preferred pace as their usual climbing. They were to take only a single step at a time, and running was not allowed. They were not allowed to stop or use the rails for support throughout the climb. An investigator accompanied each subject on his or her climb to ensure compliance and noted down the subject's climb time with a stopwatch as well as RPB and RPE using scale and heart rate at the 5 marker spots and the 2 recovery points. We used the mean value of VO_2 and VCO_2 for the 3–5 min after reaching a steady state in the respective activities for calculating energy expenditure.

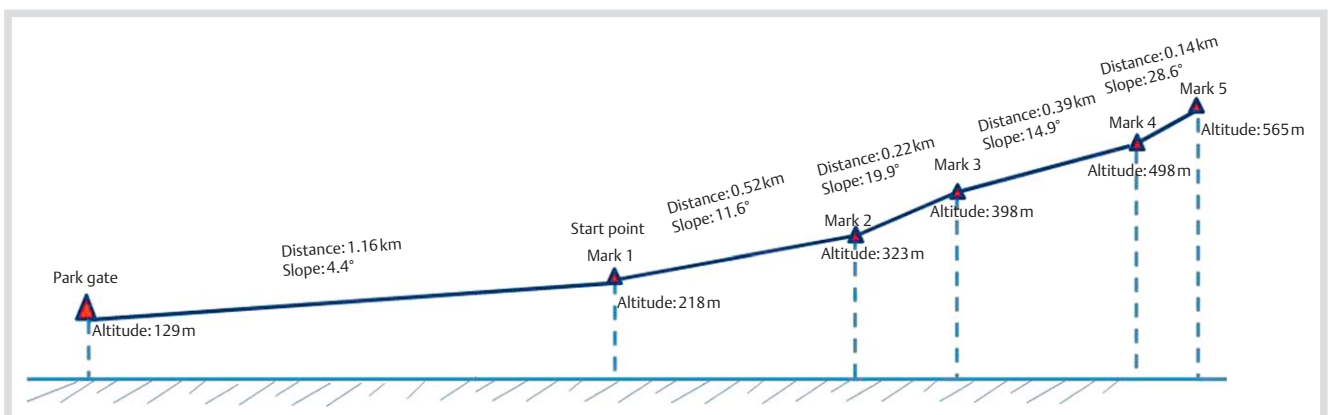


Fig. 1 Hill and energy expenditure measurement route details.

Statistical analysis

Statistical analyses were performed using SPSS16.0 software (SPSS, Inc., Chicago, IL.), and descriptive data are presented as mean±SD. All measurement indices are normally distributed. Paired samples T test was used to compare the measurement parameters responses before and after the climbing program. Statistical significance was set at $P < 0.05$. The differences in energy expenditure among the 4 slopes were analyzed by a general linear model repeated measure. To compare the main effect of the slopes, the Bonferroni test was selected. To minimize the risk of statistical type I error arising from inter-slopes comparisons, the statistical analyses were corrected using Bonferroni's adjustments, where $P < 0.05/4$ (the number of slopes). Linear regression analyses were employed to obtain the equation for calculating energy expenditure and the subjects' preferred speed when climbing. The independent factors are gender, age, height, weight, $VO_2\max$ (l/min, ml/kg/min), RPE, RPB, RER, slopes and velocity. The relation between the subjects' preferred speed and gender, age, height, weight, $VO_2\max$ (l/min, ml/kg/min) and slope was determined by regression analysis.

Result

▼ The average time of the 16 climbing sessions (ascent and decent) was 104 ± 17 min and 121 ± 17 min for males and females, respectively. Following the completion of the climbing program, body composition presented different change patterns. In males, body weight ($P = 0.007$), BMI ($P = 0.006$), whole fat mass ($P = 0.049$) and leg fat mass ($P = 0.032$) significantly decreased. Fat (%) showed a declining trend, but the difference was not significant ($P = 0.068$). Other parameters did not significantly change ($P > 0.05$). In females, fat (%) ($P = 0.010$), fat mass ($P = 0.044$), and leg fat mass ($P = 0.006$) significantly decreased, and whole muscle mass increased significantly ($P = 0.021$), while other parameters were not significantly changed (◉ Table 1).

Cardiorespiratory fitness after the intervention is shown in ◉ Table 2. In males, the absolute ($P = 0.003$) and relative ($P = 0.001$) oxygen consumption uptake and VE ($P < 0.001$) are significantly improved. In females, significant enhancements are also observed for the absolute ($P < 0.001$) and relative ($P < 0.001$) oxygen consumption uptake and VE ($P < 0.001$). Simultaneously, the HR increased insignificantly ($P = 0.039$).

Pre-intervention and post-intervention RMR values are presented in ◉ Table 3. Absolute values for RMR remained unal-

Table 1 Body composition changes following hill climbing program.

	Male (n=49)			Female (n=49)		
	before	after	P	before	after	P
body weight	73.5±10.6	72.7±9.8	0.007	59.2±8.3	58.8±8.3	0.282
BMI	24.65±3.12	24.38±2.87	0.006	22.78±2.79	22.64±2.74	0.290
fat (%)	24.4±7.4	24.0±7.1	0.068	34.0±7.2	32.9±7.8	0.010
whole fat mass (kg)	18.01±6.88	17.52±6.44	0.049	19.99±6.36	19.37±6.52	0.044
leg fat mass (kg)	4.71±1.75	4.55±1.65	0.032	6.72±1.97	6.42±2.01	0.006
whole muscle mass (kg)	53.42±5.26	53.55±5.17	0.426	37.55±3.74	38.22±4.03	0.021
leg mass (kg)	18.26±2.26	18.19±2.20	0.581	12.45±1.69	12.39±1.63	0.547
lower muscle mass (leg mass + hip mass)	26.14±3.01	25.95±2.94	0.275	17.83±2.22	17.80±2.22	0.806
bone mineral density	1.225±0.085	1.226±0.092	0.809	1.121±0.091	1.128±0.090	0.112

BMI: body mass index

Table 2 Cardiorespiratory capacity changes following hill climbing program.

	Male (n=49)			Female (n=49)		
	before	after	P	before	after	P
$VO_2\max$ (l/min)	2.350±0.332	2.478±0.343	0.003	1.529±0.240	1.683±0.286	<0.001
$VO_2\max$ (ml/min/kg)	32.68±7.14	34.68±6.77	0.001	26.32±4.87	29.03±5.09	<0.001
VE (l/min)	82.68±15.55	95.24±17.55	<0.001	51.62±9.26	66.91±12.57	<0.001
HRmax	173±16	173±14	0.832	164±13	167±11	0.039
RPE	17±2	17±2	0.102	17±2	17±2	0.078
RPB	7±2	7±2	0.077	7±2	7±2	0.852

RPE: rating of perceived exertion; RPB: rating of perceived breathlessness

Table 3 Resting metabolic rate changes following hill climbing program.

	Male (n=49)			Female (n=49)		
	before	after	P	before	after	P
VO_2 (l/min)	0.280±0.031	0.292±0.025	0.155	0.218±0.030	0.219±0.031	0.931
VCO_2 (l/min)	0.219±0.026	0.233±0.024	0.041	0.168±0.022	0.172±0.022	0.289
RER	0.79±0.07	0.80±0.05	0.449	0.77±0.06	0.79±0.05	0.329
EE (kJ/min)	5.59±0.59	5.84±0.50	0.105	4.37±0.59	4.37±0.59	0.775
EE (kJ/min/kg)	0.076±0.013	0.080±0.013	0.054	0.077±0.008	0.077±0.008	0.161
EE (kJ/min/muscle(kg))	0.101±0.013	0.109±0.013	0.051	0.118±0.013	0.113±0.013	0.161

RMR: resting metabolic rate; EE: energy expenditure

tered after climbing for both sexes. Results showed an increasing trend when RMR was expressed relative to body weight ($P=0.054$) and muscle mass ($P=0.051$) in males, and no significant change in females.

• **Table 4** described the results of preferred velocity and energy expenditure under different slope angles. The preferred velocity significantly declined as slope increased ($P<0.001$). $Y(\text{preferred speed, km/h})=5.992+(-0.009\times\text{age})+(-0.033\times\text{weight})+0.249\times(\text{female}=1, \text{ and male}=2)+0.781\times\text{VO}_2(\text{l/min})+(-0.100\times\text{slope})$ (adjusted R square=0.776). Males exhibited marginally yet significantly lower energy expenditure at a slope of 11.6° than at a slope of 14.9° ($P=0.012$) or 19.9° ($P=0.010$). Other post-hoc pairwise comparisons did not reveal significance for either males or females. Linear regression analysis to predict the energy expenditure when climbing yielded the following equation: $Y(\text{EE, kJ/min})=[1.724\times(\text{female}=1, \text{ and male}=2)+(-0.072\times\text{age})+0.106\times\text{weight}+0.024\times\text{HR}+0.136\times\text{slope}+1.487\times\text{velocity}]\times 4.2$. (adjusted R square=0.619).

Discussion

The main and novel finding of our study was that once weekly hill climbing significantly improved cardiorespiratory fitness and the energy cost of approximately 50.4 and 33.6 kJ/min under different slopes at subjects' preferred hill climbing speed in both male and female participants.

Hill climbing elicited a peak HR, which increased to above 86% and 94% HRmax attained in the laboratory in males and females, respectively. The METs under 4 slopes are approximately, but have gender difference of about 9 and 8 METs for males and females, respectively, which is similar to stair climbing. Subjects

ascended 11 stories consisting of 22 flights of stairs for a total of 180 steps (each flight of stairs has 8 steps except for the lowest flight, which has 12 steps.). Each step was 15 cm in height, for a total vertical displacement of 27.0 m. The intensity during ascent is 9.6 METs [51]. At a stepping rate of 70 step/min, METs is 8.6 [3]. Compared with other common exercise modes, the METs of hill climbing is equivalent to running at a pace of about 9.6 km/h and 8.0 km/h for males and females [1]. The METs of physical activity is ≥ 6.0 [1], thus making hill climbing at subjects' preferred velocity a vigorous-intensity physical activity. Subjects can sustain 2 or more hours of climbing, but it is difficult for them to insist on running or stair climbing the same time.

To our knowledge, this is the first study to examine energy expenditure during low-altitude hill climbing at low altitude under different slopes for health improvement. In the present study, the energy expenditures observed under different slopes at subjects' preferred speed were similar. Prior to the testing, we hypothesized that the increasing slope would increase the EE. Linear regression analysis displayed that the most important factor influencing EE was climbing velocity. In our experimental design, when the slope angles increased, the measurement distance and climbing time decreased, while climbing velocity also dropped significantly. However heart rate increased significantly in all subjects, with some even reaching their maximal heart rate. Subjects were requested to perform the preferred walking velocity, which was the maximum speed that the subjects can consistently maintain, while continually climbing. This indicated that the subjects might have no capacity to keep the same velocity as the slopes are steeper. Hence the EE appeared not to significantly increase when the slopes rose, simply due to the fact that the velocity was slower over which the participants climbed.

Table 4 Energy expenditure when climbing under 4 different slope angles.

	Slope1(11.6°) (a)	Slope2(19.9°) (b)	Slope3(14.9°) (c)	Slope4(28.6°) (d)	a vs. b	a vs. c	a vs. d	b vs. c	b vs. d	c vs. d
male (n=37)										
preferred velocity	3.35±0.43	2.26±0.35	2.82±0.32	1.64±0.32	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
VO ₂ (ml/min/kg)	30.90±5.31	33.37±7.25	33.74±7.84	33.04±7.95	0.015	0.010	0.087	0.350	0.579	0.139
METs	8.83±1.52	9.53±2.07	9.64±2.24	9.44±2.27	0.015	0.010	0.087	0.350	0.579	0.139
EE (kJ/min)	46.20±7.98	50.82±10.92	51.24±11.76	50.40±11.34	0.012	0.010	0.077	1.000	1.000	1.000
RER	0.98±0.19	1.09±0.20	1.08±0.18	1.12±0.19	0.012	0.005	<0.001	1.000	0.790	0.001
HR	148±18	160±19	168±18	172±18	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
%HRmax	86±10	92±12	97±11	100±10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
RPE	10±2	11±2	12±2	13±3	0.208	0.057	<0.001	1.000	<0.001	<0.001
RPB	2±1	3±2	4±2	5±3	0.074	0.003	<0.001	0.017	<0.001	0.075
climb time (min)	9±1	6±1	8±1	5±1						
20 min recovery EE (kJ/min)	9.20±1.76			10.63±2.52						
female (n=40)										
preferred velocity	3.21±0.39	1.96±0.32	2.40±0.43	1.47±0.33	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
VO ₂ (ml/min/kg)	30.20±5.91	29.82±6.80	29.68±7.69	28.57±7.64	0.727	0.667	0.159	0.680	0.008	0.003
METs	8.63±1.69	8.52±1.94	8.48±2.20	8.16±2.18	0.727	0.667	0.159	0.680	0.008	0.003
EE (kJ/min)	35.28±6.72	35.28±7.56	34.86±8.82	34.02±8.82	1.000	1.000	1.000	1.000	0.047	0.264
RER	1.02±0.19	1.09±0.21	1.03±0.16	1.09±0.19	0.518	1.000	0.562	0.001	1.000	<0.001
HR	156±17	165±9	170±10	173±11	0.049	0.002	<0.001	<0.001	<0.001	0.009
%HRmax (%)	94±11	100±6	102±6	105±6	0.007	<0.001	<0.001	<0.001	<0.001	0.001
RPE	12±2	13±2	13±2	15±3	1.000	0.130	<0.001	0.848	<0.001	<0.001
RPB	3±1	4±2	4±2	6±2	0.001	<0.001	<0.001	0.030	<0.001	<0.001
climb time (min)	10±1	7±1	10±2	6±1						
20 min recovery EE (kJ/min)	6.80±2.60			7.39±3.24						

%HRmax is computed by dividing climbing HR by HRmax obtained in the VO₂max measurement

At subjects' preferred velocity, energy expenditure of climbing has a gender difference of 50.4 and 33.6 kJ/min for males and females, respectively. In 10 experienced male climbers (30.0±0.9 years), energy expenditures for cross-country skiing and alpine climbing at moderate altitude under high degrees of difficulty and risk exposure lasting approximately 30 h were 57.12±2.1 kJ/min and 54.18±2.94 kJ/min, respectively [5]. In 14 participants (8 males and 6 females), stair climbing trials consisted of 86 steps and with a total vertical displacement of 14.05 m (each step averaged 16.3 cm in height) over 8 flights and 5 floors. The EE of single-step climbing used 35.7 kJ/min, and 38.64 kJ/min for double-step climbing [17]. In another stair climbing study, the EE was 42.85 kJ/min [51]. Hence, in males, the EE in hill climbing was higher than that of stair climbing, and in females, the EE was similar or lower. The EE of hill climbing was correlated with gender, age, weight, slope and velocity. The maximal steady climbing speed was also decided by gender, age, weight and slope. An energy expenditure of approximately 4200 kJ/week is associated with lower rates of cardiovascular disease (CVD) and premature mortality [13]. Thus, 90 min and 125 min of hill ascent for males and females can meet this requirement.

Contrary to our hypothesis that RMR would increase as a result of hill climbing training, the RMR was not significantly altered. Previous studies have produced inconsistent results, which reported increases ranging from 3% to 7.7% [6, 10, 32, 37, 39], no change [27, 40] or an 8% decrease in RMR [6, 40] with exercise training and those investigated primarily obese women [6], elderly people [32, 37], postmenopausal women [39, 40] and active men [10]. Long-term effects of training include increases in RMR due to increases in lean muscle mass [47]. The effects of resistance training enhanced RMR through an increase in fat-free mass 2.3 kg [10], 1.90 kg [6], 1.6 kg [37] and 1.1 kg [39]. Other resistance training studies have shown that RMR did not change significantly, even though the fat-free mass increased 2.2 kg [9]. In our study, the mean free-fat mass in previous healthy sedentary females increased 0.67 kg after hill climbing, and RMR did not significantly increase. The inconsistency might result from the different training programs and fitness levels.

After a day per week of hill climbing for 16 weeks, the whole body fat mass significantly decreased in both sexes. Leg fat mass also significantly declined 0.16 kg (3.4%) and 0.30 kg (4.5%) for males and females, respectively. The whole body muscle mass increased significantly in females, and it presented an incremental trend in males. However, although not significant, leg muscle mass showed a small decrease of 0.07 kg (0.4%) and 0.06 kg (0.5%) for males and females, respectively. Reports on the influence of aerobic exercise training on muscle mass have been equivocal, with some finding decreases [24, 52] or no influence [44, 46], and several others observing significant whole muscle hypertrophy [18, 19, 43]. The discrepancy in the literature is most likely due to variations in exercise program characteristics and subject populations. 78 healthy, previously untrained men and women aged 19–87 years were studied before and after 4 months of bicycle training (up to 45 min at 80% peak heart rate, 3–4 days/week) or control (flexibility) activity. Exercise training improved aerobic capacity 9% overall, but fat-free mass and resting metabolic rate were unchanged by training [44]. Subjects performed 12 weeks of aerobic exercise training on a cycle ergometer at an intensity of 60–80% of their maximal heart rate, for 20–45 min 3–4 times per week. Power was progressively increased in 12-W increments to optimize the training response. After training, whole muscle significantly increased by 5% and

6% for males and females, respectively [19]. However, most studies involving strength training [46] or endurance training combined strength training [42, 45] showed a significant increase in muscle mass. In our study, fat (%) only decreased by 0.4% and 1.1% for males and females, respectively. When the training program combined strength training, fat (%) decreased by 2.1% [23]. It can therefore be speculated that mixing resistance training and climbing might enhance the RMR and produce better fitness results.

Cardiorespiratory fitness has a strong, graded, inverse association with overall, CVD-related and non-CVD-related mortality [26]. An individual's VO_2max is regarded as the strongest predictors of mortality [26], and better cardiorespiratory fitness is associated with a lower risk of all-cause mortality and coronary heart disease (CHD)/CVD. Participants with a maximal aerobic capacity (MAC) of 7.9 METs or more had substantially lower rates of all-cause mortality and CHD/CVD events compared to those with a MAC of less 7.9 METs [25]. Even small improvements in physical fitness are associated with a significantly lowered risk of death [13]. Evidence for a minimum threshold of intensity for benefit is supported in many studies, but not all, and the lack of consistent findings seems to be related to the initial state of fitness and/or conditioning of the subjects [13]. Swain and Franklin reviewed 18 trials involving healthy subjects that measured VO_2max before and after exercise training and found the use of 45% oxygen uptake reserve (VO_2R) and 30% VO_2R to be a minimal effective training intensity for more fit subjects (>40 ml/min/kg) and less fit subjects (<40 ml/min/kg), respectively, despite there being no strong evidence for a threshold intensity. The VO_2R is the percentage of the difference between maximum and resting VO_2 [48]. Another comprehensive review of exercise training in runners determined that "near maximal" (i.e., 95–100% VO_2max) training intensities were needed to improve VO_2max in well trained athletes, while 70–80% VO_2max seemed to provide a sufficient stimulus in moderately trained athletes [29]. Thus, a threshold of exercise intensity may vary depending on fitness level, and it may be difficult to precisely define an exact threshold for improving cardiorespiratory fitness. The significant improvement in VO_2max reported in the present study provides evidence that just 2 h of hill climbing once a week at the subjects' preferred velocity is sufficient to enhance cardiovascular fitness in sedentary healthy adults.

Following 16-W hill climbing in the present study, the VO_2max increased 6.1% and 10.3% in males and females, respectively. In 8 sedentary young women, stair climbing was progressively increased from one ascent a day in week 1 to 5 ascents a day in weeks 7 and 8. Training took place 5 days a week on a public access staircase (199 steps), at a stepping rate of 90 steps per minute. Each ascent took about 2 min to complete. The accumulated bouts of stair climbing result in a 17.1% increase in VO_2max [4]. The degree of improvement in VO_2max was lower for hill climbing than that of stair climbing [4], but the benefits from hill climbing resulted from only once a week. Once weekly is more suitable for people who are busy and have more actual application.

Ventilation increased significantly, specifically by 29.6% and 15.2% for males and females, respectively, indicating an improvement in respiratory muscle function. This may result from expiratory pressure increasing at the beginning of expiration to take advantage of the higher flows available at higher lung volumes or from end expiratory lung volume increasing, thereby shifting the tidal volume closer to total lung capacity, at which point

higher expiratory flows can be achieved [7]. The ability to augment VE is also impeded by excess body mass [2], resulting in an altered ventilatory pattern in which higher than expected increases in respiratory rate are needed to offset a diminished ability to increase tidal volume. Therefore, hill climbing might have benefits for enhancing lung function in obese persons. In healthy males, increases in plasma interleukin-6 (IL-6) concentration during maximum sustainable voluntary ventilation are attenuated following 6-W inspiratory muscle training by $27 \pm 18\%$, and the plasma IL-6 response is dependent upon the level of respiratory muscle work and VE [31]. IL-6 is an energy sensor and acts to stimulate lipolysis, hepatic glucose output and glucose uptake [34]. It is thus speculated that the improvement of VE following the completion of the hill climbing program reflects changes in glucose metabolism, lipolysis and fat oxidation.

Conclusion

Hill climbing at subjects' preferred velocity is a vigorous-intensity physical activity for energy cost and is equivalent to running at a pace of about 9.6 km/h and 8.0 km/h for males and females. Performed once weekly, it can enhance cardiorespiratory fitness and reduce fat mass, and can therefore be considered a viable exercise for most people and suitable for promoting physical activity.

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