Health, 2016, 8, 1402-1410
http://www.scirp.org/journal/health
ISSN Online: 1949-5005
ISSN Print: 1949-4998

Practical Use of Stairs to Assess Fitness, Prescribe and Perform Physical Activity Training

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How to cite this paper: Al Kandari, J.R., Mohammad, S., Al-Hashem, R., Telahoun, G. and Barac-Nieto, M. (2016) Practical Use of Stairs to Assess Fitness, Prescribe and Perform Physical Activity Training. *Health*, **8**, 1402-1410.
http://dx.doi.org/10.4236/health.2016.813141

Received: July 1, 2016
Accepted: October 25, 2016
Published: October 28, 2016

Abstract

Aim: Evaluating climbing stairs for prescription and implementation of physical activity regimes. **Methods:** Healthy females (F, n = 14), and males (M, n = 15) participated. By climbing 100 steps of stairs with 0.173 m height, Heart rate (HR) and oxygen uptake were measured throughout the floors; Blood pressure (BP) was measured at ground and the 5th floors only. **Results:** Energy increased from 2 to 7.6 was metabolic equivalents (METs = 3.5 ml O_2/min·kg) at 17.3 m elevation in 2 min. at the 5th floor, and percent Heart Rate Reserve (%HRR) was 66.17% in F and 48.7% in M, proportional to their aerobic efforts. Average climbing efficiency was 15.8 ± 2.3% (n = 29). Aerobic capacity estimated dividing the highest work rate (17.3 Kg·m/^{2}min·Kg × 0.00239 = 0.0207 Kcal/min·Kg), by fractional effort (F = 0.6617, M = 0.487) and fractional efficiency (0.158), at 5 Kcal/L O_2 was 0.040 in F and 0.054 L O_2/Kg·min in M. Minimum training intensity reached at the 3rd floor by F. In M the highest %HRR reached was 48.7% at the 5th floor, insufficient for training. **Conclusions:** Stairs used for submaximal evaluation of aerobic capacity and for target intensity prescription. Training, levels climbed, repetitions per day (if 5, 100 Kcal per day, ascending) and number of days/week are adjusted. Full regime requires up to 7.6 METs, a total of 532 and 140 MET.min/week ascending and descending, respectively. Intensities >7.6 MET, climbing rate should be >8.65 m/min. Limiting ascent to 1 (3.5 METs) or 2 (5.5 METs) floors or only descents (2 - 3 METs) may be used for unfit subjects. This method is useful for those with no access to sophisticated facilities.

Keywords

Stair Climbing, Descent, Heart Rate Reserve, Aerobic Effort, Oxygen Cost, Work Output, Efficiency, Aerobic Capacity, Exercise Prescription, Training

1. Introduction

The Gulf Cooperation Council Countries have very high percentages of non-communicable diseases, namely, obesity, diabetes and cardiovascular diseases [1]. The United Nations identified inactivity, one of the four main risk factors for these chronic diseases [2]. The aim of this study was to explore whether climbing stairs can be used by the family physician and other healthcare professionals for evaluation, prescription and implementation of physical activity regimes (training) in various types of patients. Purpose: To measure the physiological responses in ascending stairs for both male and female subjects, and to explore the possibility of using the stairs for exercise fitness evaluation, prescription and training.

2. Methods

Healthy male and female volunteers (fourteen females F, 30.9 ± 2.86 years of age, and fifteen males M, 33.3 ± 2.72 years old) with no physical nor mental disabilities participated in the study (Table 1). The tests were conducted at Kuwait University Faculty of Medicine. Subjects ascended and descended the Faculty of Medicine, Kuwait University's five floors stairs (100 steps of 17.3 cm each, at 50% grade, total ascent of 17.3 m in 2 min, on average). Heart Rate and time elapsed were measured at every floor using Polar Watches. Energy expenditure was measured indirectly using a portable gas flow meter (Quark-b2) and gas analyzer (Cosmed, Rome, Italy) and expressed in ml O_2 $Kg^{-1}\cdot min^{-1}$ or in metabolic equivalents (1 MET = 3.5 ml O_2 $Kg^{-1}\cdot min^{-1}$), at rest and at each floor. Blood Pressure was measured at the ground and fifth floors using a sphygmomanometer and auscultation. HRmax for each subject was estimated as: 220 minus age (years). Heart rate reserve (HRR) was estimated as HRmax-resting HR for each subject. Percent HRR (%HRR) was calculated as [(measured HR − resting HR)/HRR] × 100.

3. Results

This stairs had 17.3 cm/step, 50% grade and a total of 100 steps, but any stairs can be used as long as the height per step and the number of steps are known. The subject's descriptive anthropometric data are shown in Table 1. Females were shorter, lighter and had slightly higher HR max and rest HR than males. HRR was similar in F and M.

Table 1. Anthropometry and Heart rates (HR) in males and female subjects.

Variable	Male (15) Mean ± SD	Female (14) Mean ± SD
Age	33.60 ± 10.53	30.93 ± 10.69
Height	1.72 ± 0.05	1.59 ± 0.08
Weight	82.27 ± 13.04	67.93 ± 10.99
HR Rest	74.33 ± 7.18	76.64 ± 11.30
HR Max	186.40 ± 10.53	189.07 ± 10.69
HR Reserve	112.07 ± 11.62	112.43 ± 11.09

Subjects climbed at their chosen natural rate. Statistical comparisons of HR and METS, between male and female groups in ascending and descending stairs are shown in Table 2. The MET levels increased as subjects ascended the stairs but were lower and approximately constant during descent, F exhibiting higher METs than males at each floor during descent. Comparing MET used during ascent between floors, there were significant and gradual increases at all five stair levels up to 7.6 METs in F (Figure 1). In M, the increases were significant at the first and second levels, smaller at the 3rd and 4th, reaching also 7.6 METs at the fifth floor (Figure 1). METs used at each elevation (m) are shown in Figure 2. The rate of ascent in F and M was similar and constant at each floor (8.65 m/min) and is shown in Figure 3.

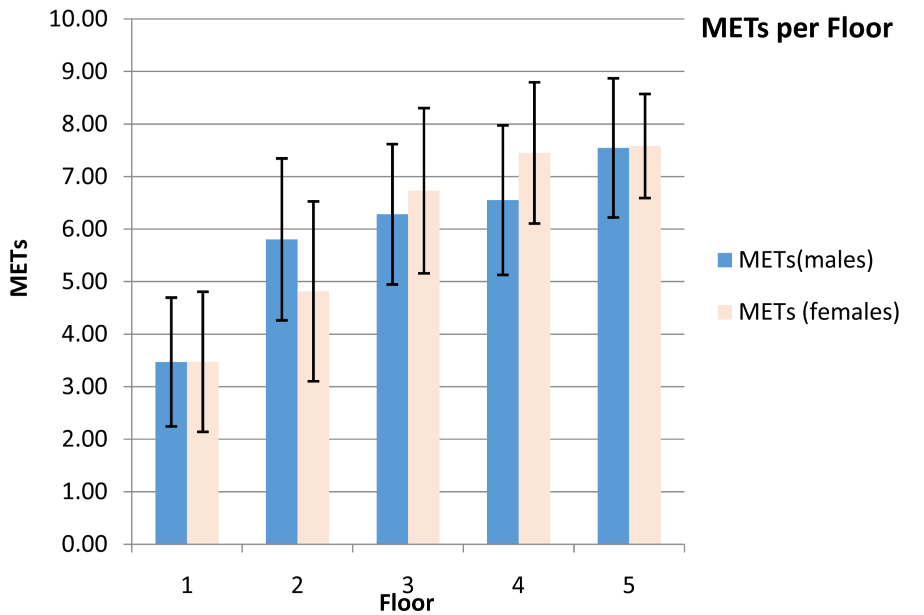


Figure 1. Energy cost (in Metabolic Equivalents (METs); 1 METs = 3.5 ml O_2 $Kg^{-1} \cdot min^{-1}$) of ascending 5 floors of stairs of 20 steps/floor, 0.173 m/step.

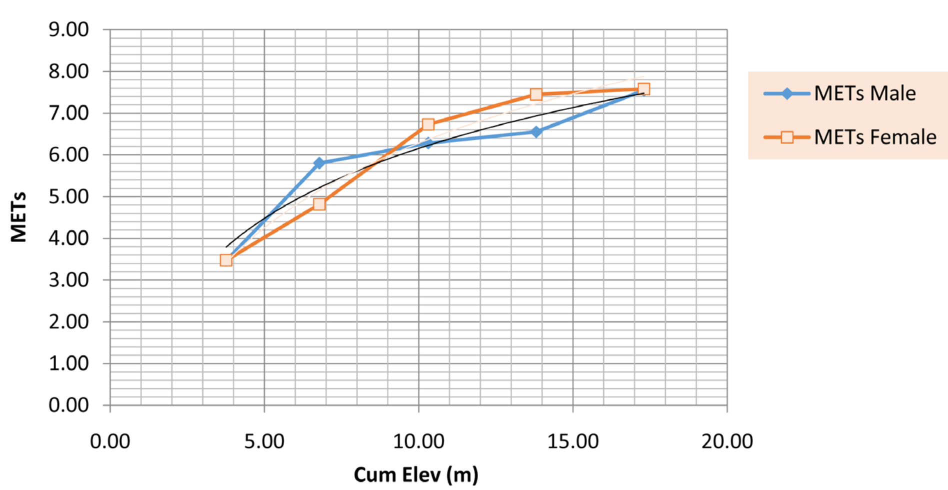


Figure 2. Energy expenditure while ascending a 17.3 m elevation stair in 2 min.

Table 2. Heart rates (HR) and energy costs (METs and ml O_2/Kg.min) of males and females while ascending and descending 5 floors of stairs with 100 steps of 0.173 m each, in 2 min after 10 min rest.

		Heart Rate			METs			VO_2 (ml/Kg/min)		
	Floor	Male ± SD	Female ± SD	Sig	Male ± SD	Female ± SD	Sig	Male ± SD	Female ± SD	Sig
Ascending	0	74.33 ± 7.18	76.64 ± 11.30	0.514	1.74 ± 0.21	1.40 ± 0.32	0.300	6.10 ± 1.75	4.89 ± 1.13	0.068
	1	103.40 ± 10.68	114.57 ± 13.33	0.019	3.47 ± 1.23	3.47 ± 1.33	0.199	12.14 ± 4.29	12.16 ± 4.67	0.992
	2	115.00 ± 11.72	126.50 ± 12.12	0.015	5.80 ± 1.54	4.81 ± 1.71	0.931	20.31 ± 5.39	16.85 ± 5.99	0.113
	3	120.13 ± 17.17	138.50 ± 12.73	0.003	6.28 ± 1.34	6.73 ± 1.57	0.933	21.99 ± 4.68	23.55 ± 5.51	0.415
	4	123.27 ± 16.43	148.57 12.01	0.000	6.55 ± 1.42	7.45 ± 1.34	0.066	22.93 ± 4.98	26.07 ± 4.71	0.092
	5	127.47 ± 20.73	151.29 ± 11.60	0.001	7.55 ± 1.32	7.58 ± 0.99	0.539	26.41 ± 4.63	26.54 ± 3.47	0.712
Descending	5r	96.33 ± 14.45	121.29 ± 12.83	0.003	2.98 ± 0.55	2.79 ± 0.32	0.574	10.44 ± 2.93	9.76 ± 2.43	0.500
	4	102.13 ± 22.80	114.93 ± 13.85	0.081	3.21 ± 0.49	3.43 ± 0.57	0.401	11.23 ± 2.99	12.02 ± 2.62	0.458
	3	99.07 ± 20.23	116.64 ± 14.30	0.012	3.27 ± 0.66	3.79 ± 0.54	0.150	11.44 ± 2.81	13.28 ± 3.14	0.107
	2	98.40 ± 18.45	117.86 ± 13.54	0.003	3.59 ± 0.75	3.57 ± 0.75	0.926	12.57 ± 3.88	12.50 ± 3.10	0.959
	1	100.33 ± 18.60	117.71 ± 14.75	0.010	3.19 ± 2.78	3.62 ± 0.61	0.210	11.17 ± 3.44	12.68 ± 2.90	0.216

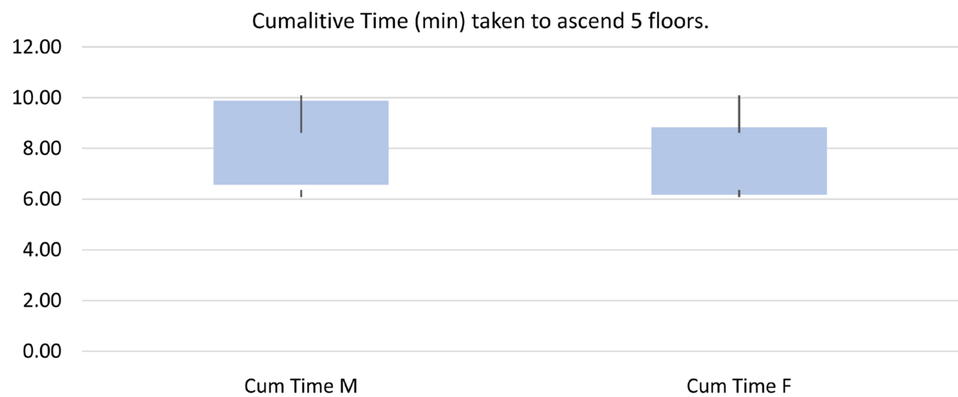
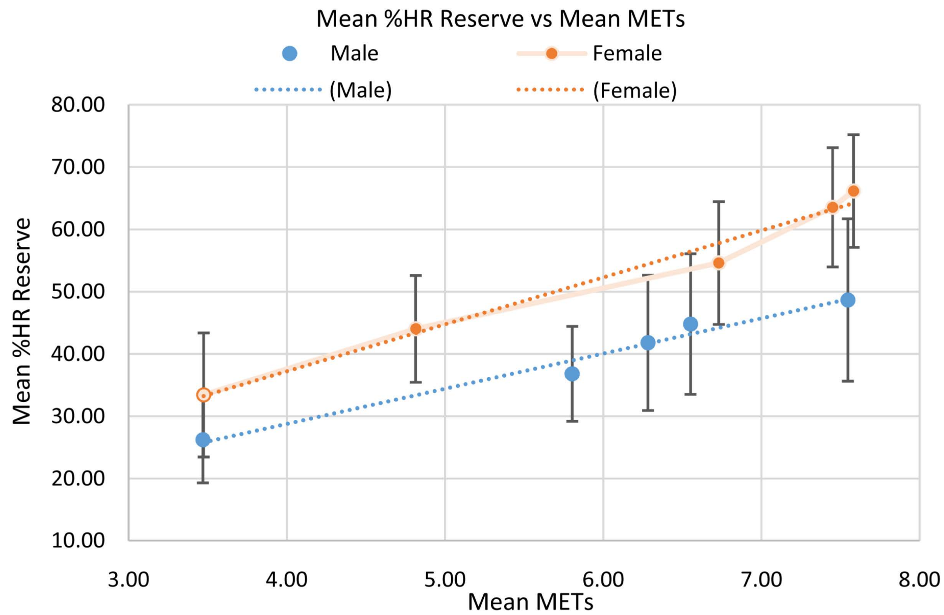


Figure 3. Time spent to ascend a 17.3 m 5 floors stairs with 20 steps/floor.

No difference in resting HR were found between F and M. HR were significantly higher after climbing each of the five stair levels in F than in M (Table 2, Figure 4(a)). The mean HR as percentage of estimated maximal at the end of each of five increasing stair levels were 55.7%, 61.9%, 64.8%, 66.6% and 68.8% in M and 60.6%, 66.9%, 73.2%, 78.6%, 80.1% in F (Figure 4(b)). Figure 4(a) shows the relationship found between the average %HRR and METs measured at each floor. The linear equations shown were the best fits found to the data.

The maximal METs that would be reached at 100%HRR, are calculated from the measured METs reached at the 5th level (7.6) divided by the fractional effort (derived from the %HRR reached for F = 0.6617 and M = 0.487), at 11.48 METs for F and at 15.6 METs for M, similar to those derived from the indicated equations (Figure 4(a)). **Maximal mechanical work output** is estimated from the mechanical work at the 5th floor (17.3 m × 1 Kg/2 min) divided by the measured fractional effort (from the %HRR



(a)

(b)

Figure 4. (a) Heart rate reserve reached at each level of energy expenditure (Mean METs) while ascending a 5 floor, 17.3 m stair; (b) Percent of maximal heat rate reached at each average level of energy expenditure while ascending a 5 floor stair.

reached F, 8.65/0.6617 = 12.98 and M, 8.65/0.487 = 17.76 Kg.m/min per Kg body weight lifted) which (×0.00239 to convert [3] Kg·m/min to Kcal/min) are 0.031 and 0.042 Kcal/Kg·min in F and M, respectively.

Efficiency of stair climbing for each subject (n = 29) is calculated dividing the measured highest rate of mechanical work output reached (8.65 Kg·m/min per Kg body weight lifted × 0.00239 = 0.021 Kcal/min per Kg body weight lifted) by the measured highest rate of energy expenditure reached (on average 0.0266 L O_2/Kg·min × 5 Kcal/L

O_2 = 0.133 Kcal/min·Kg for both F and M) yielding an average ± SE of 0.158 ± 0.023 (fractional efficiency) or 15.8% for both F and M.

Figure 5 shows the linear relationship found between %HRR and % of VO_2max (aerobic effort) in males and females indicating that %HRR is directly proportional to the aerobic effort, in both sexes.

Aerobic capacity can be estimated, when oxygen uptake is not measured, from the calculated maximal rate of work output: 0.031 (for F) and 0.042 (for M) Kcal/Kg.min. Dividing by the measured fractional efficiency of stair climbing (0.158), gives estimates of the mean maximal rate of required energy input (expenditure) in Kcal/Kg.min: 0.197 (for F) and 0.269 (for M).These divided by 5 Kcal/L O_2 result in 0.039 (in F) and 0.054 L/Kg·min (in M) maximal O_2 uptake, similar to those estimated by extrapolation of the data in Figure 4(a).

The average target training intensity in METs for females in this group, was estimated at 6.3 METS (Figure 4), using 60% of HRR, as the minimum recommended exercise training target [4]. Even if the energy costs are not measured, the elevation (m) at which 60% of HRR is reached can be easily determined. On average, females reached this training target slightly above the 3d floor (10.3 m elevation) (Figure 4(a)) but males on average, reached only 48.75% HRR at the 5th floor (17.3 m elevation), indicating that their climbing rate (8.65 m/min) should be faster (such as 10.6 m/min) if they want to use these stairs to reach 60% HRR (9.6 MET, 10.6 Kg·m/min·Kg) for effective aerobic training. The %HRR reached at the top, should be verified by direct measurement in each subject to insure that an adequate training intensity is achieved.

Systolic blood pressure increased to 140 mmHg at the 5th floor in both males and females.

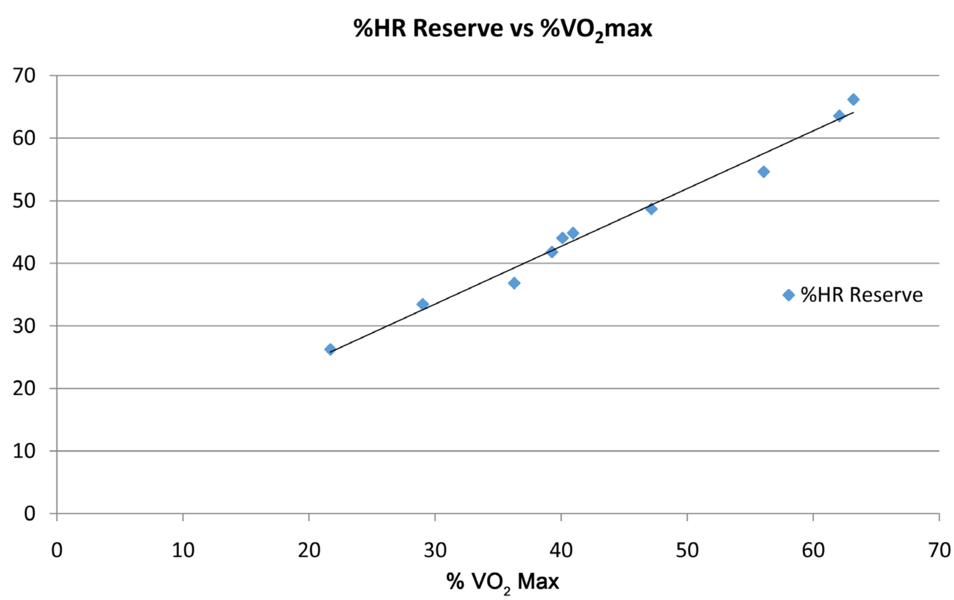


Figure 5. Relationship between percent aerobic effort (%Vo_2max) and % Heart rate reserve reached while ascending a 17.3 m, 5 floor stair in 2 min.

During stairs descent the HR was 110 to 120; %HRR was 15% and the METs used 2 to 3, in F higher than in M. F have higher HR after 10 min rest recovery than M. By alternating ascents and descents the subject practices in addition to aerobic training, a form of interval training helpful to improve balance and flexibility.

4. Discussion

Health professionals may use stairs for submaximal evaluation of physical fitness (with estimate of MET max and aerobic capacity). This is readily done when HR and VO2 are directly measured (**Figure 4(a)**), by extrapolation to 100% HRR and reading the corresponding VO_2 from the derived equations (**Figure 4(a)**). When oxygen uptake is not measured, for each individual, aerobic capacity is estimated, from the highest rate of work output reached (in Kg·m/min per Kg lifted, the corresponding fractional effort (from the highest %HRR reached), converted (×0.00239 Kcal/Kg.m) into Kcal/Kg.min and divided by the fractional efficiency of stair climbing (0.158 for these stairs), to estimate maximal energy expenditure in Kcal/min.Kg, which when divided by the caloric equivalent of oxygen, 5 Kcal/L O_2 yields the maximal L/min O_2 uptake per Kg body weight. The climbing efficiency changes little in stairs with different percent grades as the cost of horizontal displacement at each step depends on stepping rate but negligibly on horizontal displacement [5].

The rate of oxygen consumption reached after 2 min at the highest (17.3 m) level climbed by both F and M was 0.0266 L/min·Kg (0.133 Kcal/min·Kg or 9.04 Kcal/min in F weighing 68 Kg and 10.90 Kcal/min in M weighing on 82 Kg) which compared well with those in the manual of Bioenergetics for Exercise Sciences [5] and those previously reported in several studies (7.8 - 13 Kcal/min) evaluating the energy cost of stair climbing [6]. The Kcal used per min and per Kg lifted was independent of sex (0.133) and comparable with previously reported [6] stair climbing values (0.110 - 0.185). In this study, we also used the measured highest attained work rate, the fractional effort (from the %HRR reached, which we show in **Figure 5** that is directly proportional to $\%VO_2max$) and the stair climbing fractional work efficiency (at 0.158 ± 0.023 in both males and females) to estimate the aerobic capacity of the subjects, since directly measuring oxygen uptake is rarely available to the healthcare worker. The Kcal spent per step was lower in females (0.18) than in males (0.219), given their lower body weight, and again within range of previously reported values (0.2) [7].

For patients with limitations, it is likely that they would reach efforts higher than 60% (as reflected by their %HRR) at the 3rd floor compared to the healthy females in this study. Their stair climbing should be more limited (one or two floors). This can be assessed by monitoring their HR and not allowing it to reach more than 60% of HRR. Severely limited subjects may benefit by stair descents which require only 2 - 3 METs.

For exercise prescription, %HRR is plotted against cumulated floor elevation (m). The elevation at which 60% of HRR is reached [4] is estimated, for example, at 10.3 m (the 3rd floor) for an average female in this study. For the healthy males, or athletes, the velocity of stair climbing may have to be adjusted so that at the top floor at least 60% of HRR is reached.

Using a minimum recommended weekly physical activity volume of 600 MET.min per week for health maintenance [8], at an average exercise intensity of 6 METs, 100 min/week is the minimum total weekly duration of physical activity to be recommended for health maintenance. This can be broken down into sessions of about 20 min/day (5 ascents per day × 2min/ascent = 10 min going up at 7.6 METs = 76 MET.min/day and 10 min going down × 2 METs = 20 MET.min/day, for a total of 96 MET.min/day), 7 days/week frequency for a workout of 96 × 7 = 672 MET.min/week, higher than previously suggested [9]. For health enhancing effects (to lower blood pressure, reduce cholesterol, weight loss, and enhance aerobic capacity) at least double the minimum physical activity volume recommended per week (at least 1200 MET.min/week) should be used and the subject retested after 3 months.

Elevations of systolic blood pressure during stair climbing much greater or smaller than 140 mmHg, decreases in diastolic blood pressures (DBP) or increases of DBP to values higher than at rest may indicate additional pathology.

Climbing stairs can thus safely be used as a mode of physical activity and exercise training by adjusting elevation (floors) climbed, the rate of climbing (time per floor) and the repetition rate while monitoring heart rate and timing. This can be used by healthcare providers or subjects that have no access to more sophisticated facilities.

Funding

By Department of Physiology, Faculty of Medicine, Kuwait University.

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