PHYSIOLOGICAL RESPONSE TO EXERCISE WITH WEIGHT GAIN AND WEIGHT LOSS

Introduction

This report examines the extent to which the weight gain and weight loss alter the physiological response to exercise. The body requires an adequate amount of energy for muscle contractions and relaxations, metabolic reactions, and to run other physiological systems of the body according to the demand of the type and nature of the exercise. For the energy production in the body by any physiological pathways aerobically, adequate consumption of oxygen is mandatory. Energy expenditure during walking or running mainly depends on force require to support body weight, work done to redirect and accelerate the vertical displacement of body's center of mass, swinging of the limbs and muscle work to maintain stability. Farley & Mcmahon, 1992 and Kram & Taylor, 1950 studies' suggest that the energy expended to support the body weight is the prime factor of the running economy (RE). RE is the measure of a person's oxygen consumption while running at a given velocity and is expressed as the rate of oxygen consumption per distance covered (Saunders, 2004). Montoye, Kemper, Saris & Washburn (1996, p. 4) states that "if exercise is to be expressed as energy expenditure in joules or calories, body size must be taken into account".

There is no significant change in energy expenditure in the aspect of oxygen uptake, in between the pregnancy and non-pregnancy state of women while performing a same given sub-maximal exercise with weight supported for e.g. stationary cycling (Ohtake, 1988; Pernoll et. al., 1975 a). However, a significant increase in oxygen consumption is seen when a pregnant woman doing a sub-maximal exercise that involves weight bearing and movement of the body as walking, running, treadmill exercise in comparing to the same exercise in a non-pregnant state (Wolfe & Mortola, 1993). Fraley & McMahon, 1992, found the reduction in the metabolic cost in proportion to the reduced body weight they have done by using a harness system for simulating reduced gravity to the runners. These results support the idea that weight gain and weight loss have the significant effect in running economy.

This report aims to: a) measure changes in energy expenditure with weight gain or weight loss during walking and running; b) observe if these changes are more apparent when walking/ running uphill; c) measure heart rate response to exercise with weight gain and weight loss.

"The energy expended during weight bearing exercise increases directly with the body mass transported", Mc. Ardle et. al., (2000, p. 162). We hypothesized that body consumes more energy or uses more amount of oxygen when exercising with weighting and thus a fat person with greater body mass uses more oxygen while doing weight-bearing exercises like walking and running in comparison to a thin person or with de-weighting. Running involves a repetitive number of single leg stance and due to a reduced base of support, lesser limb mechanical advantage, the lower limb muscles especially knee extensors undergoing strong eccentric contractions and also concentric contractions of hamstrings, resulting in the demand for more energy. Also as more swinging of limbs and whole body movement and lifting of the body weight is high in running, we hypothesized that energy expenditure would be higher in running than in walking. Also, we hypothesized that uphill walking/running requires more energy than level walking/running as relatively more group of muscle contractions or muscle work is necessary to propel the whole body weight against gravity to acquire both horizontal plus vertical displacements.

According to the Fick principle, oxygen consumption is the product of cardiac output (Q) and arterio-venous oxygen difference $(a\text{-}v)O_2$ difference. So, there is a linear relationship between heart rate and oxygen consumption (Wilmore & Costill, 1994). We hypothesized that with weight gain more energy is required resulting in more oxygen consumption which ultimately demands the increased heart rate.

We investigated the metabolic cost of running and walking with weighted and de-weighted in a normal and 10% gradient treadmill test on the basis of measurement of whole body oxygen consumption (VO_2) and respiratory exchange ratio (RER).

METHODS AND MATERIALS

Subjects

Three subjects (all male students) who were physically fit for treadmill running volunteered to participate in the study. The experimental subjects 1, 2 and 3 ranged from 18 to 23 years of age and weighed 85.8 kg, 80.5 kg and 78 kg respectively. All the subjects were informed about the study procedures, protocol, safety measures, purpose, duration, benefits and the risk factors of the test.

Overview

The test was carried out in two weeks of time in a laboratory room. The barometric pressure and temperature in the room was 764 ± 0.5 mmHg and 20 ± 0.5^{o}c respectively. The subjects walked and ran on a calibrated treadmill normally, weighted and de-weighted. Weighted tests were done in the first week and de-weighted in the second week. In each test, only two subjects were recruited. We measured their rates of oxygen consumption, carbon dioxide production, the total volume of expired gas and heart rate on each phase of the test.

Protocol

On the first-week Subjects, 1 and 2 were recruited for 5 minutes walking and running tests respectively in a normal body weight at first and then weighted by 10% of body weight. Both walking and running were done in a normal flat and 10% gradient treadmill conditions. Walking tests were done at the speed of 6 km/h and running at 10 km/h speed. Each subject was recruited to 4 phases of each 5 minutes test; normal flat & uphill and weighted flat & uphill. Two subjects were tested alternatively so that to ensure enough rest to avoid any effect of fatigue in the study. Sample gas was collected on Douglas bag during the last minute of each phase of the test and Heart Rate (HR) at the end of each phase was measured. Sample gas was analyzed and volume of Oxygen expired (%), the volume of Carbon dioxide production (%), total volume in Douglas bag (V_E $Lmin^{-1}$) by using a dry gas meter, sample time and temperature of the sample (^0C) were measured for the study.

On the second week subject, 1 was replaced by subject 3. All the test procedures and protocol were repeated as on the first week but with the subjects de-weighted by 10% of the body weight. HR and all the measurements were taken on the same line as on the first week.

Equipment and Calculations

Before the start of each test, the subjects' weights were taken by using Jadever weight machine (JPS 2030) and resting heart rates (HR) were taken by Polar FS1 Heart Rate Monitors. The Treadmill (PAYNE) was calibrated before each test by taking the measurement of treadmill belt length and time taken to complete 10 to 20 revolutions of the belt. O_2 Analyzer (S3A/I- AEI Technologies) was calibrated to 15.8+- 0.5% and CO_2 Analyzer (CD 3A- AEI Technologies) was calibrated to 5.0+- 0.2% by using Non-Hygroscopic Soda Lime VSP-NF. Gas collecting bags (Douglas bags) were well evacuated by using Dry Gas Meter (Harvard), connected to a vacuum pump. The total volume of the collected gas sample was measured by Dry Gas Meter and its temperature was recorded by K, J Thermometer (Dick Smith Electronics). The subjects were weighted by using weight cuff jackets and de-weighted by electronic hoist connected to a fixed pulley above and was monitored by the electronic flow chart for windows version 6 (AD Instruments, Australia).

Measurement of Oxygen Consumption (VO_2):

Oxygen consumption can simply be calculated as the subtraction of the amount of oxygen exhaled ($V_E O_2$) to the amount of oxygen inhaled ($V_I O_2$), that is; $VO_2 = V_I O_2 - V_E O_2$ (Montoye et.al. 1996).

Further,

$VO_2 = (F_I O_2 * V_I) - (F_E O_2 * V_E)$, where $F_I O_2$ & $F_E O_2$ are the fraction of oxygen inspired and expired respectively.

Again,

V_I is calculated by using the Haldane Transformation,

$V_I * F_I N_2 = V_E * F_E N_2$ (Wilmore et.al., 1994).

Measurement of Respiratory Exchange Ratio (RER):

RER is the ratio of total volume of carbon dioxide produced to the total volume of oxygen consumed.

So, RER = VCO_2/VO_2 (Wilmore et.al., 1994)

Results

Overall, we found that oxygen consumption reflecting the energy expense increased in slightly less than direct proportion to the added weight and decreased in more than the reduced body weight (Table 1). We also found that energy cost is markedly higher for both walking and running in all normal, weighted and de-weighted conditions in an uphill than in a flat horizontal condition (Table 1).

Weighted and de-weighted response

Overall net energy cost increased with the increase in weight of the body by added weight and significant increment seen in running than in walking in both flat and uphill conditions (Table 1). Similarly, relative oxygen uptake decreased in direct proportion to the body weight. Respiratory exchange ratio increased very slightly in the weighted condition in walking, increased markedly in running condition (Table 1). The total volume of expired air increased significantly with added weight and in running than in walking in both flat and uphill conditions (Table 1). With reduced weight by 10% body weight, oxygen consumption reduced significantly than in weighted condition. We found a marked difference in CO_2 production between a weighted and de-weighted condition in comparison to the O_2 consumption (Table 1 & 2).

Table 1. A final result of the study: (Weighted –subject 1 & 2; total volume of inspiration & expiration, total oxygen uptake, carbon dioxide production volume, respiratory exchange ratio and relative oxygen uptake)**.**

Subject	Condition	Volume Expired ($L.min^{-1}$ at STP)	Volume Inspired ($L.min^{-1}$ at STP)	O2 Uptake (L.min at STP)	CO2 production (L.min-1 at STP)	RER	Relative O2 uptake (ml.kg.min-1)
1	Flat Normal	34.64	34.81	1.62	1.44	0.89	18.83
1	Uphill Normal	52.21	52.46	2.90	2.65	0.91	33.85
1	Flat Weighted	27.90	28.19	1.64	1.36	0.83	17.41
1	Weighted Uphill	61.87	62.15	3.13	2.85	0.91	33.23
2	Flat Normal	75.96	76.32	3.44	3.08	0.90	42.73
2	Uphill Normal	127.62	128.51	4.93	4.05	0.82	61.29
2	weighted flat	85.33	85.75	3.75	3.33	0.89	42.21
2	weighted uphill	133.00	133.05	4.79	4.73	0.99	54.07

Table 2. Final result of the study: (De-Weighted –subject 3 & 2; total volume of inspiration & expiration, total oxygen uptake, carbon dioxide production volume, respiratory exchange ratio and relative oxygen uptake)**.**

Subject	Condition	Volume Expired (L.min-1 at STP)	Volume Inspired (L.min-1 at STP)	O2 Uptake (L.min at STP)	CO2 production (L.min-1 at STP)	RER	Relative O2 uptake (ml.kg.min-1)
3	Flat Normal	50.73	50.47	1.52	1.79	1.17	19.52
3	Normal	40.39	40.63	2.24	2.00	0.89	28.71

	Uphill						
3	De-weighted flat	35.03	35.02	1.41	1.42	1.01	19.32
3	De-weighted Uphill	43.46	43.52	2.04	1.98	0.97	28.05

2	Flat Normal	74.67	75.65	3.78	2.81	0.74	46.95
2	Uphill Normal	115.21	115.16	4.40	4.45	1.01	54.65
2	De-weighted Flat	69.05	69.58	3.07	2.54	0.83	42.37
2	Uphill De-weighted	109.40	109.61	4.10	3.89	0.95	56.59

Heart rate (HR) response

HR and exercise intensity or workload is directly proportional to each other until the maximum heart rate (HR_{max}) is achieved (Williams & Wilkins, 2000). We found a proportionate increase in heart rate with the increase in exercise intensity due to the addition of weight and nature of exercise (Table 3).

Table 3. Heart Rates in different conditions in week 1 & 2.

Subject 1: Walking	HR	Subject 2: Running	HR
Rest	62	**Rest**	63
Normal/Flat	95	**Normal/Flat**	156
Normal/Uphill	108	**Normal/Uphill**	191
Weighted/Flat	98	**Weighted/Flat**	178
Weighted/Uphill	145	**Weighted/Uphill**	193

Subject 3: Walking	HR	Subject 2: Running	HR
Rest	84	**Rest**	70
Normal/Flat	118	**Normal/Flat**	165
Normal/Uphill	133	**Normal/Uphill**	186
De-Weighted/Flat	106	**De-Weighted/Flat**	166
De-Weighted/Uphill	125	**De-Weighted/Uphill**	181

Discussion

Effect of added weight

Net oxygen consumption or energy cost increased with increase in the weight of the body in overall conditions of the test (Table 1), generally supporting our first hypothesis. We could not compare the proportionate increase in energy cost with the increase in body weights as the study was done only with a 10% of body weight added. There is only slight increment in the amount of oxygen uptake in proportion to the increased weight as this study could not calculate the effect of oxygen deficit. As the subjects were tested alternatively they got enough rest in between each test and that the oxygen needs and the oxygen supply differ when a person transit from rest to exercise, (Wilmore et. al., 1994). In contrary to the other results and to our hypothesis, the result of subject 2 in weighted uphill running, oxygen uptake is lesser than in normal uphill running (Table 1). This result showed the drawbacks of the study that it could not measure the effect of oxygen deficit, as this was the last phase of the test, some muscle group might have gone to fatigue and thus could not uptake enough oxygen to generate adequate power, or the subject was using anaerobic pathways to generate energy required. However, the result of relative oxygen uptake for the same test (Table 1) has supported our hypothesis. So, overall results have supported the hypothesis of high energy requirement to exercise with weight gain.

Effect of reduced weight

Significant reduction in the total amount of oxygen uptake in de-weighted conditions of all the tests well supported our first hypothesis that de-weighting or a thin person uses relatively less energy or consumes less oxygen in performing the same level of exercise in comparison to the heavyweight person. Our reduction in oxygen uptake is lesser than the reductions reported by Farley and Mc Mahon (Farley and Mc. Mahon, 1992). This might be due to the difference in the use of weight-reducing harness system that we had used reducing system attached to the fixed pulley above in contrast to the system attached to the rolling trolley above, which reduces the energy consumption for forwarding propulsion of the body weight. Also the type of fuel, body used to generate energy makes difference in the amount of oxygen consumption. However, marked decrease in oxygen consumption has supported our hypothesis of less energy requirement to thin people as they need to overcome the lesser workload to lift and support the body weight during weight bearing exercises like walking and running.

Walking Vs Running (weighted and de-weighted)

"Supporting body weight comprises a much greater percentage of the net metabolic cost of the running than walking (74% Vs 28%)", Tuenissen, Grabowski and Kram, (2007, p=4425). Greater the body weight to be supported greater will be the ground reaction force which is in-turn associated with 4.9 folds increase in running than in walking (Biewener, Farley, Roberts and Temaner, 2004). This ground reaction force is inversely proportional to the limb muscle mechanical advantage and thus demanding the high energy cost of running than walking and again with higher cost in weighted than de-weighted. Since we had tested walking and running tests with two different individuals, we could not estimate the closest result comparing running to the walking. However, with the marked difference between the walking and running oxygen uptake with weighted and normal conditions of subjects 1 &2 who had less normal body weight difference of 5.3 kg, our results have supported our second hypothesis of higher energy cost in running than in walking. Also with the marked difference in oxygen consumption between the weighted and de-weighted run by subject 2 (Table 1 & 2), support the greater energy cost with weight during exercise.

Flat Vs Uphill

With regard to our third hypothesis, walking and running uphill increased oxygen consumption substantially. Since the center of gravity is raised in vertical displacement and thus the body demands a higher amount of energy to overcome the gravitational force and support the body weight.

Respiratory exchange ratio

The measurement of RER is highly affected by the type of food substrate to be oxidized (Wilmore et. al., 1994).Neglecting the type of fuel used to generate energy; our results of RER have supported our hypothesis of higher energy cost in weighted, running and uphill conditions than in de-weighted, walking and flat conditions. The larger amount of oxygen consumption during weighted, running and uphill conditions have resulted in the reduction of RER (Table 3 & 4) than in de-weighted conditions.

Heart Rate Response

The heart rate results have shown the linear rise in proportion to the increase in work intensity in response to the weighted conditions than in de-weighted conditions. The highest heart rate of the whole test period is recorded to be 193, associated with subject 2 running uphill test in weighted condition; (Table 5) has supported our fourth hypothesis. HR has also markedly reduced in response to the de-weighted conditions than to the weighted conditions.

Conclusion

We found that body weight causes the difference in the energy cost level in various forms of mainly weight bearing exercises like walking and running. A person with greater body weight uses a greater amount of oxygen than a thin person to do the same intensity level exercises. It takes more energy to propel body weight forward in the inclined path than to propel on a horizontal plane pathway. We found that running requires more energy consumption than walking in any weight conditions. However, calculating the energy requirements only on the basis of oxygen consumption is not an accurate way as a lot of other factors also play a marked role in energy expenditures during exercises.

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