1975

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Peter W. R. Lemon
University of Windsor

Recommended Citation

Lemon, Peter W. R., "Comparison of the energy cost of selected fire fighting tasks." (1975). *Electronic Theses and Dissertations*. 1495.
https://scholar.uwindsor.ca/etd/1495

COMPARISON OF THE ENERGY COST
OF SELECTED FIRE FIGHTING TASKS

By

PETER W.R. LEMON

A Thesis
Submitted to the Faculty of Graduate Studies
through the Faculty of Human Kinetics
in Partial Fulfillment of the Requirements
for the Degree of Master of Human Kinetics
at the University of Windsor

WINDSOR, ONTARIO

1975

ACKNOWLEDGEMENTS

It is extremely difficult to acknowledge all the individuals who contributed to the successful completion of this thesis. Sincere appreciation is expressed to Dr. R.T. Hermiston for his enduring patience and assistance in the supervision and guidance, of not only this study, but during my entire graduate experience. A special vote of thanks is due to Dr. F. J. Cerny for his constructive criticism and helpful suggestions in the analysis of data. The author's gratitude is also extended to committee members Dr. M.T. Sharratt and Dr. A. Raouf.

Further acknowledgement is directed to the City of Windsor Fire Department, specifically, Chief J. Malott, Captain R. Thornton, Lieutenant G. Spratt and the individual fire fighters who volunteered as subjects.

Finally, thanks go to colleagues, Mr. L. Leigh and Ms. L.J. Stevensen for their assistance during the data collection.

DEDICATION

This thesis is dedicated to my parents, Honor and Ken Lemon who have always been a major factor in any of my endeavours. Their endless patience, encouragement, understanding and sacrifice have made it possible for me to realize one of the more important goals of my life.

ABSTRACT

The purpose of this study was to evaluate the energy cost of four selected fire fighting tasks and the physical fitness level of professional fire fighters in order to assess the need for a physical fitness program.

Forty-five randomly selected, City of Windsor, Ontario, professional fire fighters underwent a physical fitness appraisal based on the following components of fitness: a) aerobic power, b) anaerobic power, c) body composition, and d) muscular strength. Twenty of these men engaged in the four selected work tasks at constant pre-determined work rates.

The results indicated that: (1) fire fighters perform heavy physical work (60-80% $\dot{M}VO_2$), (2) fire fighters are not different from the average male population with respect to the fitness parameters studied, (3) total net O_2 cost of "non-steady state" work based on VO_2 + measured recovery O_2 debt may be misleading when compared to "steady state" values, (4) heart rate and respiratory exchange ratio are not very precise measures of energy cost during "non-steady state" work of varying durations,

(5) body weight was directly related to energy cost and % body fat was only of secondary importance, and (6) arm strength, lower body strength and MVO_2 may be related to percent contribution of aerobic processes to total net O_2 cost, however, the results were inconclusive.

It was concluded that determination of the energy cost of "non-steady state" work is much more difficult and subject to a larger error variance than is "steady state" work. Three methods of assessment have been suggested which were unfortunately, crude at best. In addition, it was concluded that, a physical fitness program designed individually for fire fighters and specific to fire fighting might be advantageous.

Recommendations for further research were suggested relating to (1) the clarification of the O_2 deficit-recovery O_2 debt relationship, and (2) the determination of energy cost data at fires in order to partition the added stress of actual fire fighting.

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CHAPTER I

INTRODUCTION

Ischemic heart disease or coronary heart disease (CHD) as it is more frequently called has become a major health problem in many countries throughout the world. In the so-called "developed" or industrialized countries CHD leads all causes of non-accidental death among the middle and older age groups. It alone is responsible for 39% of all deaths in the United States, claiming over 700,000 lives annually (126). It has been demonstrated that there are geographical, racial, sexual and occupational differences regarding the risk of CHD (6, 24, 45, 89). The incidence and mortality rates of CHD for various sample male populations are presented in Table 1.

TABLE 1 (35,95,100)

CHD INCIDENCE RATE PER 10,000 MALES			CHD MORTALITY RATE PER 10,000 MALES		
Air Force personnel		9.1	General population		3.0-3.5
Industrial personnel		24.9	(ages 30-50 yrs.)		
General population		28.0	Firemen	a)	6.9-45.4 (95)
Firemen	a)	12.5-150.0 (95)		b)	9.0-32.0 (100)
	b)	52.5 (95)		c)	8.0 (95)
	c)	29.0 (35)			

It appears (from Table 1) that firemen experience a much higher incidence of CHD and also a higher mortality rate from this disease than the general male population.

Recently it has been reported, based on the overall death rate for firemen, that professional fire fighting is one of the most dangerous of all occupations (8) (see Table 2).

TABLE 2

ON-THE-JOB DEATH RATES (all causes)
per 10,000 MALES (8)

Manufacturing workers	10
Industrial workers	18
Non-manufacturing workers	20
Policemen	73
Firemen	87

Since firemen are involved in life-threatening situations day after day this higher than average death rate may be expected even if the optimal safety precautions are undertaken. Yet, if one examines the causes of death more closely, several interesting statistics are produced, i.e., 33% of all fire fighter deaths, for which the International Association of Fire Fighters received detailed reports in 1972, were caused by heart attacks (this was much higher than any other cause of death). A longitudinal study of the Los Angeles Fire Department (35) reported that heart attacks accounted for only 2.5% of all injuries to firemen but 25 - 75% of all deaths.

From the preceding data, it seems possible that the higher than normal incidence and mortality from CHD observed in fire fighters (Table 1) is not simply a manifestation of this dreaded disease within an isolated population, but rather it represents a significant deviation from the norm. Perhaps death from CHD may be responsible, at least partially, for the higher overall death rate observed in fire fighters.

RISK FACTORS AND CORONARY HEART DISEASE

According to the World Health Organization (WHO) the underlying cause in 90% of all cases of myocardial infarction was sclerosis of the coronary arteries caused by accumulation of lipid deposits (125). What exactly triggers this accumulation is not yet known, however various investigations (41, 45, 67, 68, 87, 89, 97, 101, 102) have demonstrated that there are certain risk factors associated with the incidence of CHD including:

1. Blood lipid levels: a) serum cholesterol,
   b) triglycerides,
2. Hypertension,
3. Obesity,
4. Heredity,

5. Smoking cigarettes,
6. Diabetes,
7. Lack of physical activity,
8. Stress,
9. Personality traits and behaviour patterns (type A & B), and
10. Certain trace elements i.e., cadmium and as yet unidentified elements in hard water.

Since the incidence and the mortality rate of CHD is much higher in fire fighters than in the general population; it is logical to assume that firemen might possess more of the so-called risk factors. However, this does not seem to be the case. In fact, it has been found that the number of CHD risk factors in fire fighters is unusually low (12, 35, 46, 70). It has been suggested that something or some activity associated with the job of fire fighting might be responsible for the high incidence of CHD (12, 35).

SUDDEN STRENUOUS EXERCISE

Data published by Barnard (11) suggest that the sudden strenuous exercise without prior warmup may be partially responsible for the increased incidence of CHD among firemen. He reported that 68% of 44 asymptomatic men (ages 21-52) exhibited ischemic electrocardiogram (ECG) changes in response to sudden strenuous work (treadmill at 9 mph and 30% grade). Barnard concluded that the adaptation of coronary blood flow to provide oxygen (O_2) to the heart was not instantaneous and that periods of ischemia may occur under such conditions, even if overt CHD was not present (11).

There are two problems with Barnard's hypothesis:

1. There are no objective data available to demonstrate that fire fighters work at an energy cost level equal to the work stress of his treadmill test, and

2. If, in fact sudden strenuous exercise produces periods of ischemia and this is a factor in the development of CHD, one might expect to find a high incidence of CHD in athletes who engage in this type of maximum work regularly, both in training and in competition. There is at present no available evidence to support this supposition.

INJURIES TO FIRE FIGHTERS WHILE ON THE JOB

Fire fighting is the occupation with the largest number of on-the-job injuries (8). Sprains and strains accounted for 37% of all injuries to fire fighters in 1971 and 54% in 1972 (8). In both cases, these minor injuries led by far any other single class of injury. The next most common injury was injury to the back. A three year study within the Los Angeles Fire Department reported 25% of all injuries were back injuries (28). Ralph (100) reported that since 1966 25% of all injuries to firemen in Canada have been back injuries. In his own department, 50% of recurrent injuries were to the back. As well, back injuries account for the greatest time lost from work of any class of injury (100).

In summary, it appears that professional fire fighting is a hazardous occupation.

1. Firemen have one of the highest death rates of all occupations,
2. Firemen have a higher incidence of CHD and mortality rate from this disease than the general population, and
3. Fire fighting has more on-the-job injuries than any other occupation.

The energy cost of professional fire fighting has not been reported as it has in numerous other occupational tasks (94). Reliable and valid test procedures for collecting these physiologic data have not been reported partly due to the difficulty of obtaining such measures. If there is a relationship between fire fighting and CHD, as has been suggested (12, 35), a thorough investigation of the energy cost of fire fighting may provide some insight into this problem.

STATEMENT OF THE PROBLEM

The purpose of this study was to:

1. Evaluate the energy cost of fire fighting,
2. Assess the physical fitness level of professional fire fighters in the City of Windsor, Ontario, and

3. Compare the level of fitness with the energy cost of fire fighting in order to evaluate the need for a physical fitness program.

More specifically, this study was designed to investigate the following:

1. The energy cost of 4 fire fighting tasks in terms of total O_2 cost and kilocalorie equivalent, multiples of resting metabolism (METS), O_2 consumption (aerobic component), recovery O_2 (anaerobic component), respiratory exchange ratio (RE), heart rate (HR) and length of work periods, during a number of the more physically strenuous training drills as designed by the Fire Department Training School in the City of Windsor, Ontario (115).

2. The fitness levels of the fire fighters based on the following components of fitness:

   a) Aerobic Power,
   b) Anaerobic Power,
   c) Body Composition, and
   d) Muscular Strength

NEED FOR THE STUDY

Professional fire fighters are exposed day after day to physically and emotionally strenuous work. Since their own lives and the lives of countless others are frequently at stake, it seems imperative that these professional firemen remain in excellent physical condition. However, before it is possible to state the minimum level of physical conditioning required and whether or not a causal relation exists between fire fighting and CHD a thorough assessment of the energy cost of fire fighting is necessary. Once this has been determined as well as an evaluation of the present level of fitness of firemen, a decision can be made as to whether or not a higher level of fitness would be beneficial.

There is no generally accepted procedure for the assessment of the energy cost of "non-steady state" work (85, 90). In order to make an accurate assessment of this type of work both the aerobic and the anaerobic contributions to the total work cost must be determined. The data of Davies (36) provide support for this concept. It has been demonstrated that in a weight supported work task where efficiency is similar in all subjects (i.e., bicycling) a specific workload requires approximately the same $\dot{V}O_2$ in all subjects (6, 42). Yet, Davies (36) observed that this was not necessarily so above 900 kpm. He found that the more fit subjects had significantly higher $\dot{V}O_2$'s during the work period above 900 kpm, but that this difference disappeared when the anaerobic component (O_2 equivalents of lactic acid) was added to the $\dot{V}O_2$ of all subjects. With this in mind, one wonders if trained individuals might be able to complete a strenuous work task utilizing aerobic processes to a greater extent and therefore anaerobic processes to a lesser extent than their untrained counterparts.

If this is indeed the case, it would be advantageous for fire fighters to maintain a high level of fitness since an individual who is able to supply a greater percentage of the total O_2 requirement aerobically can be expected to work longer at the same intensity, or to work more strenuously for the same period of time than his less fortunate counterpart. The advantages of this phenomenon are obvious especially in a physically demanding life threatening situation such as fire fighting. In addition, assuming that a period of cardiac ischemia occurs during strenuous work, as Barnard has suggested (11), this effect may be reduced in a fire fighter with a higher $\dot{M}VO_2$ since a strenuous task will demand a relatively smaller percentage of his maximum work capacity.

HYPOTHESES

For the purpose of investigating the problem the following hypotheses were constructed:

1. It was hypothesized that the completion of each of the 4 work tasks (p. 48-51) would result in no significant differences in total net O_2 cost and that each task

would not differ significantly from pre-exercise values. $(H_0: a_1=a_2=a_3=a_4=a_5)$.

2. It was hypothesized that irrespective of $M\dot{V}O_2$ ($ml \cdot kg^{-1}$), i.e. $< 40\ ml \cdot kg^{-1}$ and $\geq 40\ ml \cdot kg^{-1}$, the aerobic component of each task would not differ significantly. $(H_0: b_1=b_2)$

3. It was hypothesized that irrespective of $M\dot{V}O_2$ ($ml \cdot kg^{-1}$), i.e., $< 40\ ml \cdot kg^{-1}$ and $\geq 40\ ml \cdot kg^{-1}$, the anaerobic component of each task would not differ significantly. $(H_0: c_1=c_2)$.

In the event of rejection of any or all of the proposed hypotheses the following alternative hypotheses were constructed:

1. H_1: $a_1 \neq a_2 \neq a_3 \neq a_4 \neq a_5$
2. H_1: $b_1 \neq b_2$
3. H_1: $c_1 \neq c_2$

DEFINITIONS OF TERMINOLOGY

For the purpose of this study, the following definitions will apply:

1. Maximum Oxygen Uptake ($M\dot{V}O_2$, maximum aerobic power, $\dot{V}O_2$ max.): maximal quantity of O_2 which an individual can consume per minute while working assuming steady state (requires two minutes at least). This parameter is probably most representative when related to individual body weight, i.e., millilitres·kilograms^{-1}·minute^{-1}.

2. Maximum Recovery Oxygen Debt (maximum anaerobic power): maximal quantity of O_2 which an individual can consume during 6 minutes of recovery from a work bout, in excess of pre-exercise O_2 consumption for an equivalent 6 minute period.
3. Percent Body Fat: percentage of body mass that is fat as predicted from four subcutaneous fat measurements:
   a) triceps,
   b) subscapular,
   c) abdominal, and
   d) suprailiac.
4. Hand Grip Strength: maximal strength in kilograms (kg), as measured by a hand grip cable tensiometer.
5. Arm Strength: maximal strength in kg, as measured by the apparatus described in the text (p. 44).
6. Lower Body Strength: maximal strength in kg, as measured by the apparatus described in the text (p. 46).
7. Aerobic Component: quantity of O_2 consumed by a working individual during the work period.
8. Anaerobic Component: quantity of O_2 consumed during 6 minutes of recovery from a work bout, in excess of pre-exercise O_2 consumption for an equivalent period of time (includes O_2 bound to blood and myoglobin at the time of work).

9. Total Net Oxygen Cost (total energy expenditure, total net energy cost): sum of aerobic component plus anaerobic component.

10. Oxygen Deficit: the calculated O_2 requirement of a work bout minus the measured O_2 uptake during the work.

11. Oxygen Debt: quantity of O_2 consumed during 6 minutes of recovery, in excess of pre-exercise O_2 consumption for an equivalent 6 minute period. If the increased temperature, epinephrine, cardiac and respiratory effects are minimal (as they probably are in moderate work of short duration) then recovery O_2 debt is equal to, or close to O_2 deficit.

12. METS (multiples of resting metabolic rate): 1 met is equal to the O_2 consumption at rest: approximately 0.250 $l \cdot min^{-1}$ or 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$. Therefore, 10 mets = 2.5 $l \cdot min^{-1}$ or 35 $ml \cdot kg^{-1} \cdot min^{-1}$.

13. Caloric Cost: total net O_2 cost ($l \cdot min^{-1}$) x 5.0*.

14. Respiratory Exchange Ratio (RE): the ratio of CO_2 %age produced less CO_2 intake/O_2 %age consumed.

15. Coronary Heart Disease (coronary artery disease, CHD): occlusive disease of the coronary arteries that results in a limitation of the blood flow to the heart muscle. When this becomes critical,

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*See Appendix B.

necrosis of heart muscle occurs resulting in a myocardial infarction. The process of occlusion is caused mainly by atherosclerosis, a condition where the deposition of fatty material and scar tissue results in thickening of the arterial wall with consequent narrowing of the arterial lumen. This process is usually gradual, beginning in childhood or adolescence and taking years to reach a critical level.

16. Fire Fighting Tasks (T1-T4): the four most strenuous work tasks which fire fighters perform routinely, as assessed by the men themselves. These tasks were performed under training conditions which simulated actual fire fighting as much as possible. For practical reasons, however, fires were not part of the simulation.

CHAPTER II

REVIEW OF RELATED LITERATURE

ENERGY EXPENDITURE AND STRESS

There is no doubt that professional fire fighters perform very strenuous physical work. Barnard (12) reported heart rates of 150-195 beats per minute for two of three hours of actual fire fighting. If one examines some of the work tasks that fire fighters routinely carry out, heart rate responses of 150-195 bpm are certainly possible. For instance, a fire fighter wears gear in excess of 60 pounds, he is required to drag hoses (which weigh 60 pounds when empty and 120-150 pounds when full of water) distances up to 200 feet, to carry these hoses up ladders, to carry and raise ladders weighing 20-200 pounds and to carry people (many unconscious) out of burning buildings or down ladders (115).

Compounding this physically strenuous work is the very emotionally stressful situations a fire fighter must cope with; the fire bell that rings while a man is sleeping; driving a truck on ice or during a blizzard and of course; the situations at the fire, i.e., building collapse, people trapped, etc. Barnard (12) reported increases in heart rate of 20-35 percent

15 seconds after the fire alarm sounded. As well, he observed increases of similar magnitude when the fire fighters actually reached the fire (12). Typically, this type of excited response is associated with a massive discharge of catecholamines (12). Since it has been shown (30) that catecholamines can disrupt the endothelial lining of the artery wall, it is possible that these excited responses to stressful situations may increase the risk of CHD in fire fighters.

Greenisen (53) presented data demonstrating that physical fitness (as measured by body composition, cardiac efficiency and vital capacity) is related to anxiety level (as measured by urinary catecholamines) in the individual confronted with a hazardous task (parachuting). The lower fitness groups showed significant increases over their normal catecholamine values while the fit group showed no change. In addition, Chin (23) found that non-exercised controls and light exercise groups demonstrated higher levels of plasma catecholamines than the moderate and heavy trained groups when exposed to 28,000 feet simulated altitude. He reasoned that the lower sympathoadrenal response in the moderate and heavy trained groups was the result of a less severe stressing effect of the altitude on the more fit individuals.

ENVIRONMENT

As well as being forced to carry out strenuous physical work and being exposed to emotionally stressful situations, a fire fighter must work in environments which are far from favorable. Generally, it is very hot (as high as 1,000 degrees centigrade (92,111)) and obviously very humid. These factors can increase the work of the heart tremendously (18). From this extremely hot environment, a fire fighter may be exposed alternately to extreme cold, i.e., in the winter. This rapid change in temperature might cause vasoconstriction of the coronary arteries (7, 31) thereby reducing the myocardial O_2 supply and resulting in possible necrosis of heart cells. As well, a fire fighter is constantly working in an environment of reduced O_2 content, usually 5-15 percent, (12 percent can cause death of living heart cells (71)) and increased carbon monoxide content (5,000-20,000 parts per million). The 100-300 parts per million found in heavy automobile traffic or industrial areas is considered to be an important variable in the development of CHD (35). The reason carbon monoxide is so dangerous is the fact that it attaches to hemoglobin (respiratory pigment of red blood cells responsible for carrying the major portion of the O_2 from the lungs to the tissues) at the same place as O_2, but with 200-300 times the binding power of O_2 (6). The presence of high levels of CO may therefore reduce the O_2 carrying capacity of the blood, even if there is sufficient O_2 available in the environment. When the blood cells containing CO reach the heart, heart muscle is deprived of O_2 and necrosis of heart cells may occur.

PHYSICAL FITNESS

Astrand (6) provides us with perhaps the best single definition of physical fitness, "Fitness consists of the ability of the organism to maintain the various internal equilibria as closely as possible to the resting state during strenuous exercise and to restore promptly after exercise equilibria which have been disturbed".

It is extremely difficult to assess the major determinants of physical performance, mainly because the demands of different activities vary greatly. However, the physiologic event common to all physical performance is the contraction of skeletal muscle. Triggered by nerve impulses adenosine triphosphate (ATP), (the universal intracellular carrier of chemical energy), loses one of its phosphate radicals becoming ADP and inorganic phosphate. The splitting of this phosphate provides energy for muscular contraction. Since the store of ATP in the muscles is very limited a rapid resynthesis is essential in order to maintain activity for any length of time. The breakdown of high energy creatine phosphate (CP) supplies the energy necessary for the resynthesis of ADP and inorganic phosphate to ATP. Unfortunately, CP stores are also very limited and must be restored continuously. ATP and CP stores (internal energy stores) can cover the energy demand for only a few seconds of heavy work (57). For the purpose of continuously supplying energy after the initial internal energy stores are depleted two additional sources are available:

1. The aerobic oxidation of carbohydrates (CHO), fats and proteins $\longrightarrow CO_2 + H_2O + ATP$.
2. The anaerobic oxidation of glycogen or glucose $\longrightarrow$ lactic acid + ATP.

Aerobic oxidation is favoured, provided oxygenated blood can be delivered to and utilized by the tissues at a rate sufficient to meet the uptake demanded by the workload. On the other hand, if the demand of the contractile units exceed the uptake, then anaerobic oxidation is utilized to cover the O_2 deficit.

Maximum Oxygen Uptake ($M\dot{V}O_2$)

$M\dot{V}O_2$ or maximum aerobic power is often considered the best single measure of a person's physical fitness, provided one is concerned with the capacity of an individual for prolonged work (6). Since fires may burn for many hours aerobic oxidation is a major physiologic contributor to the energy supply during fire fighting.

In essence $M\dot{V}O_2$ is a measure of the ability of the heart to pump blood to the lungs, of the blood to pick up O_2 from the alveoli, of the heart to pump this oxygenated blood to the exercising muscles, of the muscles to take up and utilize the O_2 delivered and of the blood to return CO_2 to the lungs. The assessment of $M\dot{V}O_2$ is therefore basically a measure of the functional capacity of a person's circulatory, respiratory and metabolic systems. The power of this system can be measured by the amount of atmospheric O_2 utilized (inspired - expired O_2) in litres·minute^{-1} or millilitres·kilograms^{-1}·minute^{-1}. It is well established that training can increase $M\dot{V}O_2$ by as much as 20-25 percent (6, 42, 108) and that the observed increases may be of even greater magnitude if related to body weight or if preceded by bed rest (106).

Maximum Recovery Oxygen Debt

Maximum recovery O_2 debt is another factor to be considered in the total energy cost of a piece of work. $M\dot{V}O_2$ contributes very little to the energy demands of activities requiring maximal effort which last for very short periods of time (under two minutes (6)). The maximum recovery O_2 debt or the maximum anaerobic power is the important factor for these brief intense efforts.

The power of this anaerobic system has been measured in a number of ways by previous investigators including:

1. The concentration of lactate in the active muscle (muscle biopsy technique (15)). This technique is a relatively complex medical procedure involving extraction of a small portion of the active muscle tissue from the subject. For this reason and because the procedure involves considerable discomfort for the subject many laboratories do not employ this method.
2. Many scientists have however been able to use lactate accumulation as an indicator of anaerobic power by the indirect method of measuring blood lactate (mg %), provided:
    a) the work is greater than 50-60% $M\dot{V}O_2$,
    b) the work is of sufficient duration, and
    c) sufficient time is allowed for diffusion of lactate from the muscle to the blood (highest blood lactate values are usually found between 5-10 minutes of recovery (6, 51).

    This technique is relatively simple and is employed in most studies where anaerobiosis is involved (90). However, recently this technique has become unpopular because of its indirect nature. Various studies (40, 63) have demonstrated that muscle and blood lactate can be vastly different. It appears that it is extremely difficult to calculate the actual anaerobic energy yield from the concentration of circulating lactate in the blood since the values may not reflect muscle lactate values but be caused by other factors (i.e., slower or faster diffusion rate from cells to the blood, metabolization of blood lactate by cardiac muscle (72) and by skeletal muscle (21), rate of resynthesis of lactate back to glycogen in the liver (105) and kidneys (71) etc.). For these reasons blood lactate should be regarded as only an indication of the envolvement of anaerobic processes and not an exact measurement of cellular costs.

3. The amount of O_2 utilized during recovery minus resting O_2 consumption for the equivalent period of time. Krogh and Lindhard (76) noticed that $\dot{V}O_2$ was elevated during recovery following exercise and attributed this raised metabolism to the O_2 deficit created during the transition from rest to exercise. Hill (60) suggested that there might be a relationship between the increased $\dot{V}O_2$ during recovery and the anaerobic

biochemical events that had been described previously by Fletcher and Hopkins (44). However, Hill (60) incorrectly attributed the recovery O_2 debt solely to the oxidation of lactic acid. In 1933, Margaria (81) demonstrated that the increased $\dot{V}O_2$ following exercise could be subdivided into three components.

a) A fast component of exponential nature (approximately 30 seconds). This portion of recovery O_2 debt is referred to as alactic because it is not related to lactate production but rather refers to the O_2 stores in the body (blood, myoglobin etc.) as well as the utilization of ATP and CP stores.

b) A slower component which is also exponential (approximately 15 minutes). This portion of the recovery O_2 debt is referred to as the lactic phase because it represents the O_2 required for the oxidative removal of lactate and its subsequent reconversion to glycogen.

c) A very slowly decreasing component lasting 1 hour or more which Margaria interpreted as "increase of resting metabolism" caused by exercise.

In the same study Margaria (81) presented data demonstrating that for the first 2.5 litres of recovery O_2 debt no increase in lactate could be shown. This suggests that the alactic sources may alone account for the first 2.5 litres of recovery O_2 debt. This is in agreement with Christensen (25) who found that alactic sources are most important during work of short duration since no significant increase in lactate concentration occurs in spite of the presence of a recovery O_2 debt. More recently others (85, 62, 74, 83, 120) have also observed this phenomenon. Wasserman (118) concluded that the fraction of recovery O_2 debt accounted for by the pyruvate-lactate mechanism (Pasteur effect) depends on work intensity. He found that a recovery O_2 debt developed at all work rates but at moderate work rates the lactate production was very small and usually insignificant. This lack of relationship between lactate production and moderate workloads has been suggested by others (6, 74, 81). It appears therefore, that with moderate work of short duration a recovery O_2 debt which can be measured can occur (perhaps indicating a contribution to the energy cost of the piece of work) without a resulting accumulation of lactate.

The magnitude of the measured recovery O_2 debt must be viewed with caution for several reasons:

1. The time in which the recovery O_2 debt is measured,
2. The baseline employed,
3. Elevated tissue temperature,
4. Effect of epinephrine,
5. Increased cardiac and respiratory processes, and
6. Various other factors that may affect the results significantly.

This anaerobic component of fitness could be particularly important for fire fighters because the O_2 content of the environment in which they work is frequently below the normal 20.93% (35). As a result anaerobic processes may be utilized earlier in a work task by a fire fighter under these conditions.

Percent Body Fat

Since the performance of most strenuous physical tasks are related to both body size and body composition, a discussion of the major determinants of physical performance would be incomplete without the inclusion of these physical parameters.

Two methods for the determination of percent body fat are widely used:

1. Underwater Weighing (39): using the Archimedes principle, specific gravity of the body is calculated (specific gravity = $\frac{\text{dry weight}}{\text{loss of weight in water}}$).

This density is then corrected for the contribution of residual lung volume (nitrogen washout of lungs). After the corrected specific gravity is obtained, percent body fat is derived from tables (29).

2. Measurement of Subcutaneous Fat Folds (58): Body fat can be predicted from the sum of fat fold measurements. This method of prediction correlates highly with underwater weighing and is much easier to employ.

Muscular Strength

Muscular strength must also be considered as a major determinant of physical performance (6). It is believed that during static work at approximately 60 percent maximal voluntary contraction (MVC), a muscle's blood flow is occluded by the contraction of the muscle against the vessels providing its blood supply (39). When this occurs, muscle metabolites build up, fatigue sets in and in a short period of time the muscular contraction must stop. Below 60 percent MVC, a muscular contraction can be held much longer. Similar results have been observed during dynamic work (59). It stands to reason therefore, that the stronger a muscle is, the longer it will be able to contract at a given submaximal intensity (below 60 percent). Shephard provided support for this belief (109). He found that the greater the knee extension strength of a group of cyclists the less the accumulation of lactate during a ride at 80% $M\dot{V}O_2$. This suggests that by strengthening the leg muscles it may be possible to decrease the anaerobic contribution of a work task where leg strength is important by increasing the aerobic contribution. Since countless studies have demonstrated increases in strength utilizing the overload principle strength training may reduce the relative stress of work of this type.

There are two main methods of strength measurement:

1. <u>Dynamic</u>: The maximum load which can be moved once, through a specified range of motion of a joint with the body in some defined position (13).
2. <u>Static</u>: The maximum effective force that can be applied once to a fixed object from a defined, immobile position (10).

Dynamic measurement is probably the method of choice however the effectiveness of its use is reduced for several reasons:

a) Dynamic movement will be limited by the weakest angle of pull of muscle (unless the resistance changes as the muscle contracts),

b) Speed of movement affects power and with dynamic measurement this is difficult to control, and

c) Most apparatus are complex and expensive.

Static measurement may be more appropriate for most studies for the following reasons:

a) It is less time consuming and less fatiguing for the subject (one single contraction is usually sufficient),

b) The variable of speed of movement is eliminated, and

c) The apparatus are less complex in construction and less expensive.

The major disadvantage is that since strength is dependent on the angle of pull of muscle as well as speed and since measurement in static evaluation is determined at one angle, the weakest point of a dynamic exercise may be eliminated. However, this weakness can be reduced by measuring at the strongest point of the muscle's range of motion.

In summary, it appears that static measurement "if performed in well defined easily reproducible position of joints will give constant results even if repeated with intervals of several days" (3).

It is known that strength is affected by two interacting related factors:

1. The length at which a muscle is working, and
2. The angle of pull of muscle (39).

TRAINING

It has been suggested (89, 114) that regular physical activity will prolong life, however there is little controlled evidence to support this belief. There are longtitudinal studies underway at the present time investigating this hypothesis (91). Yet there is at present no conclusive evidence that physical conditioning or reconditioning reduces the changes of suffering a coronary attack or death if one occurs, although clearly the literature suggests that many of the so-called risk factors, mentioned earlier, can be reduced by increases in physical conditioning.

Firemen as a group, do not seem to possess to any great extent, the normal risk factors associated with CHD, yet they do have a very high incidence of CHD. Perhaps the possible beneficial training effects of regular exercise that reduce the risk factors in the general population will offer similar protection for the particular kind of CHD that firemen experience, whatever its cause. In any event, there is conclusive evidence that regular physical exercise:

a) helps prevent musculoskeletal injuries by strengthening muscles (38, 54, 41), bones (6), ligaments and tendons (1, 116),

b) reduces body weight (if diet is held constant (87)),

c) improves work capacity (104, 106), and

d) helps restore self confidence and enjoyment of living (87).

Clearly all of these training effects would benefit professional fire fighters.

Astrand (6) states that one aim of regular training is to achieve a physical condition and degree of fitness that are well above that required for the routine job. This not only means that a standard work bout will be handled more easily but also that there is a larger "emergency reserve" when needed.

Wyndham (127) found that young men with maximal oxygen uptakes of 30 $ml \cdot kg^{-1} \cdot min^{-1}$ were capable of only moderate work and that heavy work was performed better by men with M$\dot{V}O_2$s greater than 45 $ml \cdot kg^{-1} \cdot min^{-1}$. The data of Cooper (31) (Table 3) are representative of the results of many others (6, 20, 42, 108, 127).

TABLE 3

FITNESS CATEGORIES FOR MEN

($ml \cdot kg^{-1} \cdot min^{-1}$)

Years	30	30-39	40-49	50+
I Very Poor	25.0	25.0	25.0	
II Poor	25.0-33.7	25.0-30.1	25.0-26.4	25.0
III Fair	33.8-42.5	30.2-39.1	26.5-35.4	25.0-33.7
IV Good	42.6-51.5	39.2-48.0	25.5-45.0	33.8-43.0
V Excellent	51.6+	48.1+	45.1+	43.1+

ENERGY COST OF ACTIVITIES

A review of the literature relating to the caloric cost of various activities shows that many scientists have documented work task energy costs. Direct calorimetry presented immense practical difficulties, therefore most of the early published data employed indirect calorimetry. However, these early studies were limited because of the design characteristics of the standard open circuit method. The development of the Kofranyi-Michaelis respirometer (75), a light portable unit which measures flow rates directly and simultaneously diverts a small fraction (0.3-0.6%) into a small rubber bag for subsequent gas analysis, made task evaluation more feasible. Passmore and Durnin (94) compiled perhaps the most exhaustive report on human energy expenditure using this technique. They reported mainly on daily and occupational tasks. Many others (9, 79, 82) have reported on specific sport activities.

Care must be taken when determining energy cost and metabolic rate because such variables as body size, skill of the performer (efficiency), physical effects of the collection apparatus, environmental conditions and work rate may affect the results significantly. In the past the severity of the work has been measured in litres of O_2 or kilocalories per unit time, METS or simply as a percentage of $M\dot{V}O_2$. Since the system performing the work is the muscle mass, a more logical classification might be litres·unit of time^{-1}·kg lean body weight^{-1} or kcal·unit of time^{-1}·kg lean body weight^{-1}.

The linear increase of heart rate in relation to $\dot{V}O_2$ is well established (6, 42). As a result, HR has been employed in many studies as an indication of the degree of stress involved (5, 18). The development of light-weight devices capable of transmitting impulses by radiotelemetry has eliminated cables and allowed scientists to study man under types of work stress never before possible. It must be remembered however, that HR alone, may not indicate severity of the work because of other factors, i.e., emotion or drug effects. Admittedly, the value of HR during "non-steady state" work is not as valid as during "steady state" work however, knowledge of this variable would lend support to other parameters of work stress.

Respiratory exchange ratio (RE) provides a reasonably accurate determination of the particular fuel being oxidized at rest or during "steady state" work (39), i.e., a value of 1.0 indicates carbohydrate, 0.75 indicates mainly fat and 0.85 indicates some mixture of the two. Christensen (35) concluded the following factors determine the participation of fat and carbohydrates during work:

1. the diet,
2. the duration of the work, and
3. the intensity of the work in relation to the subject's $M\dot{V}O_2$.

He concluded that the utilization of carbohydrates depends on the availability of O_2; the higher the involvement of the anaerobic processes, the higher the carbohydrate utilization. During "non-steady state" work a temporary metabolic acidosis may be produced, to which the body responds by hyperventilation, i.e., more CO_2 is exhaled than is being formed metabolically (39). It is not unusual to find RE in excess of 1.5 during heavy work. Issekutz (64) concluded that an RE greater than 1.0 is a good indication of the participation of anaerobic processes during work.

KINETICS OF $\dot{V}O_2$ FROM REST TO WORK

It has been demonstrated by Margaria (84) and substantiated by Davies (37) and Whipp (121) that the $\dot{V}O_2$ curve during the transition from rest to work is an exponential function, directly related to work intensity and characterized by a half-time (t½) of 30 seconds. These results tend to indicate as Margaria (86) suggested that:

1. the kinetics of $\dot{V}O_2$ is directly related to the rate of splitting of the high energy phosphates in the muscles, and
2. while the intracellular oxidative reactions can be started at a rate dictated by the energy requirement of the working muscles, the upper limit of the $\dot{V}O_2$ is probably set by other factors, i.e., the availability of O_2 at the tissue level or by the transport capacity of O_2 to the tissues.

O_2 DEFICIT - RECOVERY O_2 DEBT RELATIONSHIP

Since the early work of Krogh and Lindhard (76) there has been tremendous variability in the magnitude of measured recovery O_2 debt following maximal work or exercise. Values ranging from 4 to 22 litres (90) have been reported. It is difficult to accept that an O_2 deficit of this magnitude could be tolerated even by a highly motivated well-trained athlete. A number of studies have compared O_2 deficit to recovery O_2 debt and found that measured recovery O_2 debts are consistently greater than the actual O_2 deficit (2, 24, 26, 55, 56, 57, 73, 78). There have been a number of reasons suggested for this difference including:

1. three different baselines for the determination of O_2 debt have been used in various studies (basal, pre-exercise and light exercise).

2. additional possible factors contributing to the raised $\dot{V}O_2$ during recovery (113).
   a) additional energy requirement of respiratory muscles,
   b) increased work of the heart,
   c) maintaining increased systemic circulation,
   d) increased metabolism due to raised temperature (Q_{10} effect),
   e) metabolic turnover and synthesis,
   f) Na^+, K^+, Ca^{++} transport, and
   g) tissue repair.
3. the anaerobic system may be less efficient than the aerobic system.

The use of different baselines for O_2 debt determination has led to varied debt collection periods (ranging from a few minutes to several hours). Some of these collections include Margaria's third component (81) and some do not. The importance of the baseline for $\dot{V}O_2$ to recovery O_2 debt determinations was alluded to by Margaria (81). However, there is still no general agreement regarding which baseline is used. Pre-exercise is probably the most commonly used and yields reproducible results (113). However, both basal and light exercise have been used in recent studies (14, 113). Until agreement is reached and all collections are identical interpretation from one study to another is impossible.

It has been demonstrated (69, 113) that the effect of 2(a) above is negligible because ventilation decreases rapidly after exercise. For similar reasons 2(b) and 2(c) probably produce little effect (69, 108). The effect of 2(d) is probably varied depending on the duration and intensity of the work. The more severe and the longer the duration the greater the Q_{10} effect. Claremont (26) calculated that approximately 33% of the measured recovery $\dot{V}O_2$ was due to the Q_{10} effect following prolonged exercise (60 minutes) at 40-60% $M\dot{V}O_2$. Since these relationships need further confirmation and 2(e)-2(g) have never been quantified it is extremely difficult to determine their impact on recovery $\dot{V}O_2$.

Asmussen (1) published data demonstrating that the efficiency of the anaerobic system is about 50% that of the aerobic system. Hermansen (57) reasoned that 2 moles of lactic acid are formed from 1 mole of glucose with an energy liberation of approximately 55 kcal or roughly 11 litres of O_2. Since 1 mole of O_2 removes only 2 moles of lactic acid it would require 22.4 litres of O_2 to remove 2 moles (180 grams) of lactic acid. Various others have found a similar efficiency of alactic sources (99) although the reasoning for this phenomenon is more obscure. In summary it appears that measured recovery O_2 debt is somewhat larger than O_2 deficit (approximately 2X) probably due to a combination of the inefficiency of the anaerobic processes, factor 2(e)-2(g) (above) and perhaps some other unknown factor or factors.

Recently a number of investigators have studied the recovery O_2 debt phenomenon and it's relationship to O_2 deficit (96, 99, 119). The results of their work has helped to clarify the recovery O_2 debt concept. There is general agreement concerning the existence of the three components during recovery suggested by Margaria (81), however a slight modification is necessary. In some cases only two components are detectable. A fast component which is completed in about 2 minutes (99) and a second component (the remainder of the total debt) which is completed in 5-15 minutes (119, 121), 8 minutes (99), 5 (34) or 6 minutes (96). These findings disagree with the 1 hour or more that Margaria observed for repayment of the total debt. The discrepancy is probably explained at least partially by the lower work levels of the recent studies as compared to the earlier work. Since it has been suggested that at light to moderate workloads (6, 74, 81) or with work of short duration (83, 120) blood lactic acid changes are negligible, it is generally assumed that the recovery O_2 debts incurred in this manner are largely alactic.

As well, it appears that Margaria's very slowly decreasing third component is probably only detectable after severe or prolonged work and is related to the Q_{10} effect, metabolic turnover and synthesis, Na^+, K^+, Ca^{++} transport, tissue repair and possibly other unknown factors, as mentioned earlier. Hence with light to moderate work tasks or work tasks of short duration, the lactic component of the recovery O_2 debt is minimal and Margaria's third component is probably non-existent. It appears that debt collection periods between 2-10 minutes should adequately represent the recovery O_2 debt after work of this nature. Based on the present evidence, it has become apparent that the classical O_2 deficit - recovery O_2 debt ratio of 1:1 is inaccurate and that the relationship between these two is much more complicated than was originally thought.

Since the early work O_2 deficit - recovery O_2 debt ratios of 1:1.2 - 1:2.0 have been reported by various investigators (2, 24, 55, 56, 78). Recently Piiper (99) published data providing an explanation for these discrepancies:

1. When the total increment above pre-exercise values was considered (8 minutes recovery O_2 debt collection) the O_2 deficit - recovery O_2 debt ratio was 1:2.0.

2. When the recovery O_2 debt for two minutes was considered the ratio was 1:1.5.
3. When only the fast component (alactic) was considered the ratio was 1:1.2.

In conclusion, it appears that there is some interplay between O_2 deficit and recovery O_2 debt however, the relationship is masked by a number of other factors. The ratios of 1:1.2 for the alactic component and 1:1.5 for a 2 minute debt are probably closer to the actual relationship during work of very short duration (< 30 seconds) than a ratio of 1:2.0 because the lactic component and Margaria's third component are virtually eliminated. However, as the lactic component becomes more of a factor or the work is prolonged the ratio of 1:2.0 is probably more accurate.

CHAPTER III

METHODOLOGY

SUBJECTS

Forty-five healthy male professional fire fighters employed by the City of Windsor, Ontario fire department were selected, on a voluntary basis, to undergo part A of this study, i.e., physical fitness appraisal (Table 4). After this part of the study was completed 20 of these firemen were selected to participate in part B of the study, i.e., energy cost assessment (Table 5). These men were chosen such that, two groups were created:

1. those fire fighters whose $M\dot{V}O_2$ was < 40 ml·kg^{-1}, and
2. those fire fighters whose $M\dot{V}O_2$ was ≥ 40 ml·kg^{-1}.

Some of the men were familiar with the physical fitness appraisal tests or similar testing procedures because the City of Windsor requires each prospective recruit to undergo testing to determine level of physical fitness before being admitted into the department (80). However, for some of the men it had been years since they had performed these tests and because the older members had never experienced the test procedures, a period of accommodation to all

TABLE 4

MEAN AND STANDARD DEVIATION VALUES DESCRIBING THE PHYSICAL CHARACTERISTICS OF PROFESSIONAL FIRE FIGHTERS

AGE GROUP	20-29 YRS	30-39 YRS	40-49 YRS	TOTAL
N	15	15	15	45
AGE (yrs)	27.27 ± 1.39	33.47 ± 2.77	44.13 ± 3.37	34.96 ± 2.51
HEIGHT (cm)	178.01 ± 4.10	177.63 ± 3.93	178.73 ± 4.97	178.12 ± 4.33
WEIGHT (kg)	81.21 ± 7.16	85.28 ± 6.78	85.26 ± 11.52	83.92 ± 8.49
BSA (m^2)	1.98 ± 0.10	2.03 ± 0.08	2.04 ± 0.14	2.02 ± 0.11
% BODY FAT	18.36 ± 4.91	18.47 ± 3.62	20.79 ± 4.54	19.21 ± 4.36
FFWT (kg)	56.15 ± 5.55	69.47 ± 5.55	67.16 ± 6.48	64.26 ± 5.86
PRE-EX MR ($l \cdot min^{-1}$)	0.370 ± 0.046[1]	0.371 ± 0.059[2]	0.383 ± 0.036[3]	0.375 ± 0.047[4]
$\dot{M}VO_2$ ($ml \cdot kg^{-1}$)	43.06 ± 4.57	40.31 ± 5.18	31.88 ± 5.60	38.42 ± 5.12
MAX HR (bpm)	187.43 ± 7.86	184.12 ± 8.37	- -	186.03 ± 8.12[5]
MAX DEBT ($ml \cdot kg^{-1}$)	80.40 ± 16.60[1]	78.30 ± 9.99[2]	67.21 ± 8.59[3]	75.30 ± 11.73[4]
TM TO EXHAUS (sec)	85.12 ± 18.37	77.73 ± 18.49	35.27 ± 11.40	66.04 ± 16.09
RT HD GRIP (kg)	37.40 ± 10.09	40.73 ± 9.49	33.67 ± 4.85	37.27 ± 8.14
LT HD GRIP (kg)	34.80 ± 8.24	37.40 ± 9.58	35.13 ± 8.53	35.78 ± 8.78
ARM STR (kg)	145.20 ± 16.58	138.93 ± 24.04	129.00 ± 22.01	137.71 ± 20.88
LOW BODY STR (kg)	493.13 ±112.47	413.73 ± 55.09	315.67 ±124.66	407.51 ± 97.41

[1] Based on an N of 12. [2] Based on an N of 14. [3] Based on an N of 9. [4] Based on an N of 35.
[5] Based on an N of 30.

TABLE 5

MEAN AND STANDARD DEVIATION VALUES DESCRIBING
THE PHYSICAL CHARACTERISTICS OF PROFESSIONAL FIRE FIGHTERS
WHO PARTICIPATED IN THE ENERGY COST ASSESSMENT
(N=10)

WORK TASK	AERIAL LD CLIMB	RESCUE "VICTIM"	DRAGGING HOSE	LADDER RAISE
AGE (yrs)	30.70 ± 4.40	30.70 ± 5.18	31.00 ± 6.27	31.60 ± 5.95
HEIGHT (cm)	176.50 ± 4.62	181.10 ± 1.84	180.60 ± 2.23	178.88 ± 4.04
WEIGHT (kg)	84.04 ± 8.62	85.35 ± 7.83	82.55 ± 8.92	85.42 ± 7.38
BSA (m^2)	2.01 ± 0.11	2.05 ± 0.07	2.03 ± 0.10	2.04 ± 0.09
% BODY FAT	19.47 ± 4.94	18.36 ± 3.82	18.76 ± 3.93	18.22 ± 4.71
FFWT (kg)	67.57 ± 7.19	69.64 ± 6.85	67.02 ± 7.66	69.92 ± 7.90
PRE-EX MR ($l \cdot min^{-1}$)	0.344 ± 0.042	0.365 ± 0.030	0.354 ± 0.033	0.354 ± 0.032
$\dot{M}VO_2$ ($ml \cdot kg^{-1}$)	40.68 ± 6.13	42.20 ± 6.49	40.23 ± 6.61	40.56 ± 6.72
MAX HR (bpm)	188.70 ± 6.25	184.20 ± 10.15	187.40 ± 7.34	185.40 ± 8.24
TM TO EXHAUS (sec)	79.90 ± 17.39	86.10 ± 24.01	83.40 ± 24.24	77.10 ± 18.28
MAX DEBT ($ml \cdot kg^{-1}$)	74.09 ± 10.33	76.39 ± 11.59	78.90 ± 13.47	72.77 ± 6.64
RT HD GRIP (kg)	43.10 ± 13.09	42.50 ± 11.29	36.90 ± 8.24	40.10 ± 10.52
LT HD GRIP (kg)	40.60 ± 11.82	38.60 ± 11.14	34.30 ± 8.23	39.10 ± 8.71
ARM STR (kg)	138.80 ± 24.27	149.60 ± 22.64	137.50 ± 17.69	146.90 ± 22.19
LOW BODY STR (kg)	419.90 ± 85.96	461.20 ±100.29	457.90 ± 93.92	472.40 ±117.02

procedures, was provided for all subjects. None of the men had undergone the energy cost procedures however, all had experienced and were very familiar with the specific tasks employed, as they were required to carry out these procedures regularly, both in training and on the job.

PROCEDURE

Part A Physical Fitness Appraisal

All fire fighters underwent a complete physical examination by their family physician before undergoing any testing.

Aerobic Power ($\dot{M}VO_2$): Two tests were employed to measure aerobic power, a maximal test for those fire fighters under 40 years of age and a submaximal predictive test for those over 40. The submaximal test was employed with the older fire fighters because it was felt unwise to subject these men to a maximal exercise test without medical supervision and without prior knowledge of their exercise tolerance.

1. the maximal aerobic power of each fire fighter between the ages of 20-39 years (N=30) was assessed employing the Bruce multistage treadmill test. At three minute intervals the speed and grade of the treadmill[1] were increased as

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[1] Quinton Instruments, Model #2472, Seattle, Wash.

outlined by Bruce (20). Direct measurement of $\dot{M}VO_2$ was determined by collection and analysis of expired gas (N=20). The test was continued until no further increments in HR were observed after increased workload or until the subject felt he was unable to continue. Consecutive minute samples of expired gas were collected as the subject approached maximal HR (predicted for age range) and continued until the test terminated. HR was monitored throughout the test and during 6 minutes of recovery by means of a 3 lead ECG (C5-C5R).

2. The maximal aerobic power of each fire fighter between the ages of 40-49 years (N=15) was predicted from the HR response to a standard workload on a bicycle ergometer[2] (6) and corrected for age (4). The work period was 6 minutes at either 600, 900 or 1200 kpm, such that a steady state condition existed within the range of 125-165 beats per minute (bpm). HR was monitored throughout the test and during 6 minutes of recovery by means of a 3 lead ECG (C5-C5R).

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[2] Quinton-Monark ergometer, Model #850.

<u>Anaerobic Power</u> (maximum oxygen debt): The maximal anaerobic power of each fire fighter was assessed, employing a modified (unpublished data) Cureton treadmill test (29). The subjects ran to volitional fatigue on a treadmill at 8 mph and 12% grade. Time to exhaustion and a 6 minute recovery O_2 debt were recorded. As required in the recovery O_2 debt calculations pre-exercise $\dot{V}O_2$ for 6 minutes was subtracted from the total O_2 collected.

<u>Muscular Strength</u>: The maximal muscular strength of each fire fighter was assessed employing three static measurements; hand grip (117), arm (43) and lower body (27):

1. The subjects were asked to contract a maximal force, with each hand on a hand grip cable tensiometer which had previously been calibrated with known weights. A one minute rest was allowed between two maximal contractions. The greater of the two contractions was recorded as the subject's maximal grip strength (Figure 2).
2. The following apparatus was designed to measure arm strength (Figure 3). The overall action was similar to a chinup. Each subject's feet were held firmly in place on the floor by placing them under a padded metal bar fixed securely two inches above the floor via eye blots. Fifty pound weights were placed against each subject's

STRENGTH MEASUREMENTS

FIGURE I
LOWER BODY

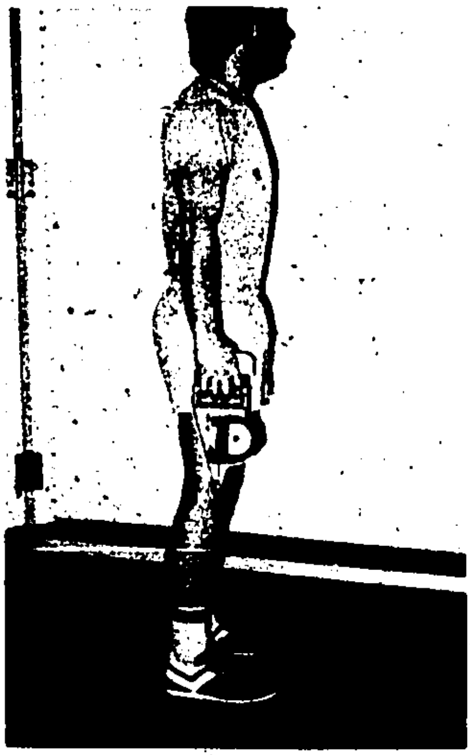

FIGURE 2 HAND GRIP

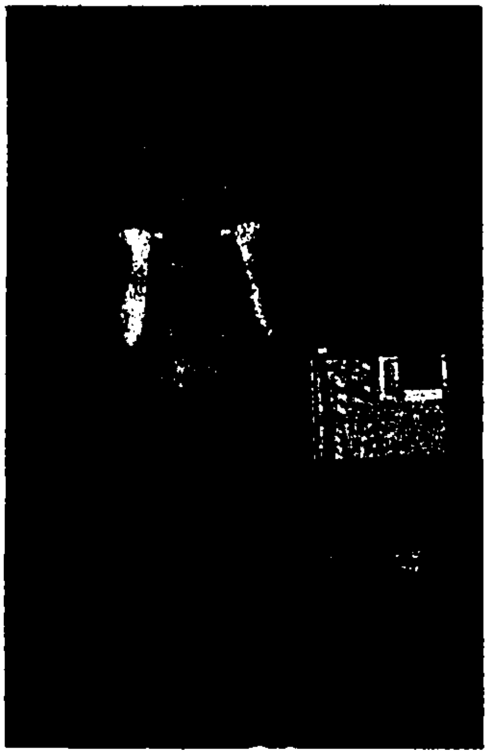

FIGURE 3 ARM

heels to provide further stabilization. Another bar (hand bar) was hung securely from a beam in the ceiling via heavy duty chain. A 1500 pound capacity load cell was connected in series between the chain and the hand bar. It was possible to adjust the height of the hand bar, so that each subject's strength was tested at the same angle (approximately 90 degrees) (43). Each subject grasped the hand bar using the reverse grip (palms facing himself) and attempted to lift himself into the air by flexion at the elbow joint. A one minute rest was allowed between 2 maximal contractions. The greater of the two was recorded as the subject's maximal arm strength.

3. The following apparatus was designed to measure lower body strength (Figure 1). The overall action was similar to the movement employed when training on a leg press machine[3]. A bar with two boots attached was firmly secured to the floor via heavy duty chain and an eye bolt. The same 1500 lb. capacity load cell as above was connected in series between the chain and the eye bolt. Each subject sat on the floor with his back against a wall, his legs

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[3] Universal Gym Machines, Model IL, Fresno, California.

SUBCUTANEOUS FAT FOLD MEASUREMENTS

FIGURE 4 TRICEPS

FIGURE 5 SUBSCAPULAR

FIGURE 6 SUPRAILIAC

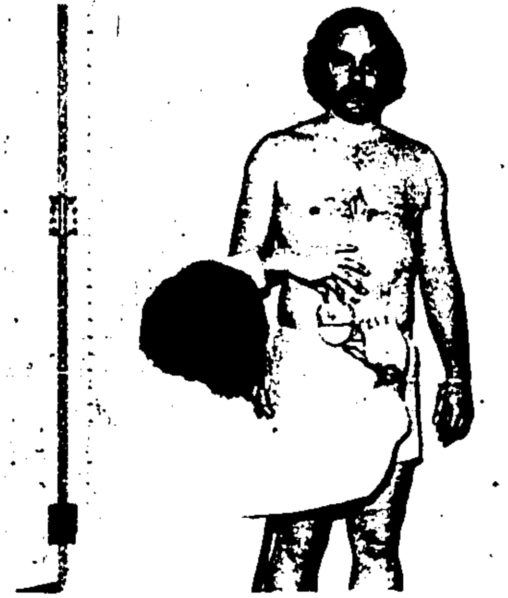

FIGURE 7 ABDOMINAL

straddling the apparatus, his hands on the floor, his knees flexed at an angle of 115 degrees (27) and his feet strapped to the boots. The subjects were then asked to attempt to horizontally extend their legs toward the opposite side of the room. A one minute rest was allowed between two maximal extensions. The greater of the two was recorded as the subject's maximal lower body strength.

Body Composition: Lange fat fold calipers[4] were employed to determine the fat fold thickness (Figures 4, 5, 6, 7) at four sites (triceps, subscapular, suprailiac and abdominal). Height and weight were also recorded. Based on percent body fat and total body weight fat free weight (lean body mass) was calculated.

Part B Energy Cost Assessment

The following four routine work tasks (T1-T4) were selected as being representative of the more physically strenuous tasks that fire fighters are required to perform (115):

1. Ascent and descent of an aerial ladder (75 feet, 68 degrees) at a rate of 79 rungs per minute (90 feet per minute) (Figure 8).

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[4] Cambridge Scientific Industries, Model #H4-8, Cambridge, Maryland.

2. Rescue of a "victim" (dummy 34 kg.) from a third storey window (24 feet) at a rate of 48 rungs per minute (48 feet per minute) (Figure 9).
3. Dragging 2½ inch hose 200 feet at a rate of 400 feet per minute (Figure 10).
4. Raise extension ladder (91 kg) to a 5th storey window (45 feet) (Figure 11).

The energy costs of these four work tasks were assessed using the following physiologic parameters:

1. Total net O_2 cost and kilocalorie equivalent,
2. VO_2 (aerobic component),
3. 6 minute recovery O_2 debt (anaerobic component),
4. RE (Respiratory Exchange Ratio),
5. HR (Heart rate),
6. Length of work periods, and
7. Level of physical fitness, i.e. MVO_2, max. debt, % body fat, muscular strength.

HR was monitored during the work tasks by radiotelemetry technique. VO_2 was measured, both during the work tasks and for 6 minutes of recovery, employing portable equipment (Figures 8-11). RE, METS and caloric cost were calculated for each task.

FIRE FIGHTING TASKS

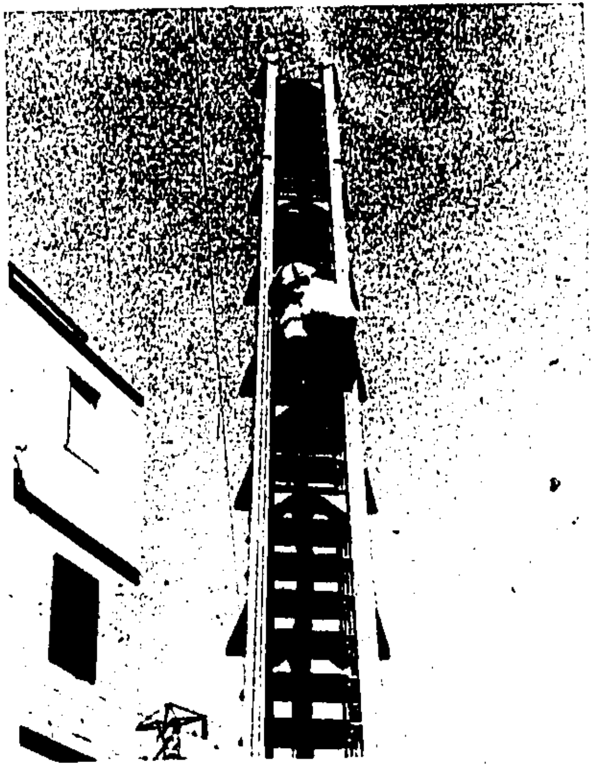

FIGURE 8 AERIAL LADDER CLIMB

FIGURE 9
RESCUE VICTIM

FIGURE 10 DRAG HOSE

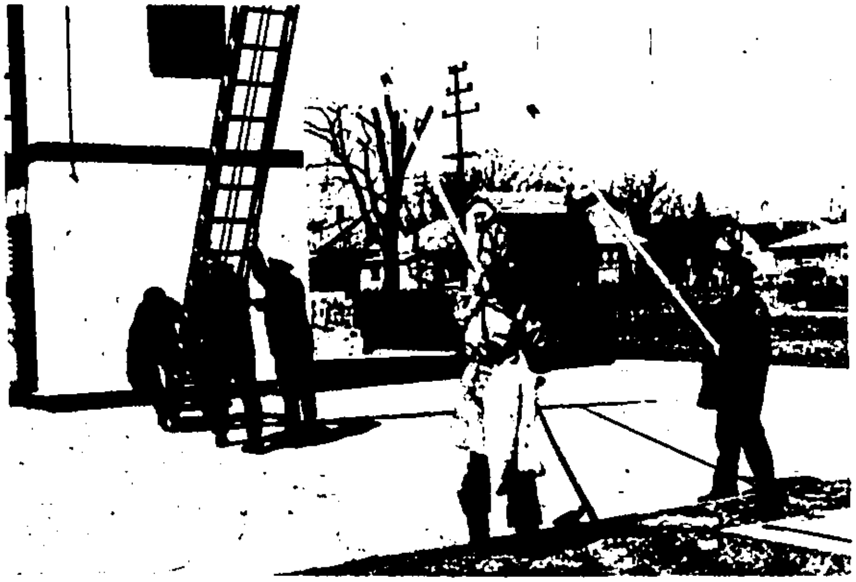

FIGURE 11 RAISE LADDER

Standardization of the Work Tasks

Previous to the actual testing situation, a number of subjects (N=14) completed each of the work tasks at "fire fighting speed", in order to determine the average period at which a fire fighter routinely carrys out these tasks (the times selected for each task above were based on the mean times of this testing). In order to prevent large discrepancies in the work rate a buzzer system was set up, such that each fire fighter was required to step on a rung or pass a stake in the ground at a set cadence.

MEASUREMENT PROCEDURES

Oxygen Uptake ($\dot{V}O_2$) measurements, both in the laboratory and in the field were made using expired gas samples which were collected in 150 litre neoprene gas bags. After thorough mixing, 50 millilitre gas samples were drawn from these gas bags with well-lubricated matched glass syringes. Subsequently these gas samples were analyzed chemically, in duplicate employing a Gallenkamp-Lloyd Gas Analyzer[5]. Only duplicates that were within 0.05 percent were accepted.

Recovery Oxygen Debt (6 minutes): Maximum O_2 debt measurement in the laboratory was made using expired gas samples which were collected in a Collins[6]

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[5] Instrumentation Associates Inc., Model #Can Lab G1891-1C, New York, N.Y.

[6] W.E. Collins Inc., Model #P-1800, Braintree, Mass.

chain-compensated 350 litre gasometer and 250 litre neoprene gas bags when necessary. Recovery O_2 debts in the field were collected in similar 250 litre gas bags. 50 millilitre gas samples were also drawn and analyzed in duplicate.

Pre-exercise $\dot{V}O_2$

Each subject breathed for 7 minutes through a Collins low resistance valve connected via plastic tubing to a 50 litre gas bag. During the last 2 minutes expired gas was collected and $\dot{V}O_2$ was calculated using the technique stated above. The 5 minute period before the actual collection of expired gas was employed to:

1. negate the effect of the dead space within the system, and
2. allow the subject to relax and establish a normal breathing pattern.

Heart Rate (HR): was recorded throughout each laboratory testing session on a Hewlett Packard recorder[7] by means of a 3 lead ECG (C5-C5R). During the work tasks HR was recorded in a similar manner by radiotelemetry[8].

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[7] Hewlett Packard, Model #1500B, Palo Alto, California.

[8] Fritz Hellige and Co., Model #115004, West Germany.

Respiratory Exchange Ratio (RE): was calculated for each work task by the ratio of CO_2 %age produced-CO_2 intake/O_2 %age consumed.

Hand Grip Strength: was measured in kg by means of a hand grip cable tensiometer[9], previously calibrated with known weights.

Arm and Lower Body Strength: was determined by means of a 1500 pound capacity load cell[10] and recorded on a Beckman 2 channel recorder[11] which was calibrated twice daily with known weights. The results were recorded in pounds and converted to kilograms.

Lean Body Weight (Fat Free Weight): was determined using the method described by Hermiston and Faulkner (58) and calculated according to the formula:

$$LBWT = WT - (\% \text{ Fat} \times WT \times 1/100)$$

where: LBWT = Lean Body Weight

WT = Body Weight

% Fat = 5.783 + 0.153 X Σ 4 Fat Fold Sites

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[9] Pacific Scientific Co., Model #T5166, Bell Garden, California.

[10] BLH Electronics Inc., Model #4361, Waltham, Mass.

[11] Beckman Instruments Inc., Type RP Dynograph, Schiller Park, Illinois.

VALIDITY, RELIABILITY AND REPRODUCIBILITY

Validity is claimed for all measurement techniques because each represents either a standard technique which has been employed in the literature or a logical progression from previous work, i.e., strength measures and debt collections.

Physical Fitness Appraisal

The measurements were repeated on the same individual on two separate occasions with 20 subjects randomly selected from a population of fire fighters.

Reproducibility was established by paired t analyses for the 20 duplicate determinations (124). The results are presented in Table 6.

Reliability was established by determining the coefficients of reliability for the twenty duplicate determinations (124). These data are presented in Table 7.

Energy Cost Assessment

The measurements were repeated on five of the subjects on two separate occasions. Reproducibility was established by paired t analyses for the five duplicate determinations (124). The results are presented in Table 6.

Since only five duplicate determinations were measured pooling of the data would be necessary to obtain reliability coefficients. Since the work tasks

TABLE 6

MEAN, STANDARD DEVIATION AND PAIRED t VALUES

PART A PHYSICAL FITNESS APPRAISAL

	TEST 1	TEST 2	t(.95,19) =2.093
M$\dot{V}O_2$ (ml·kg^{-1})	40.57 ± 5.28	40.34 ± 5.01	0.610
MAX DEBT (ml·kg^{-1})	78.84 ± 12.20	77.24 ± 13.45	2.670*
% BODY FAT	20.41 ± 5.01	20.37 ± 5.09	0.230
LT HD GRIP STR (kg)	42.98 ± 10.42	44.11 ± 9.98	1.617
RT HD GRIP STR (kg)	44.16 ± 8.67	43.87 ± 8.42	1.340
LOW BODY STR (kg)	140.27 ± 20.41	142.68 ± 22.78	1.873
ARM STR (kg)	398.10 ± 65.29	401.02 ± 61.74	1.475

*$P < 0.05$

PART B ENERGY COST ASSESSMENT

	TEST 1		TEST 2		t(.95,4)= 2.776
TASK VO_2 (1)	2.192	1.41	2.136	1.24	0.540
TASK DEBT (1)	2.272	0.76	2.218	0.98	2.460
TASK TOTAL NET O_2 (1)	3.690	1.90	3.690	1.70	2.620
TASK HR	134.400	16.10	135.800	23.24	0.305
TASK RE	0.990	0.07	0.98	0.06	0.283
TASK TIME (sec)	46.200	31.76	44.70	30.75	2.326

*$P < 0.05$

TABLE 7

RELIABILITY COEFFICIENTS FOR 20 TEST-RETEST DETERMINATIONS OF PHYSICAL FITNESS APPRAISAL TESTS

TEST	RELIABILITY COEFFICIENT
$\dot{M}VO_2$ ($ml \cdot kg^{-1}$)	0.95
MAX DEBT ($ml \cdot kg^{-1}$)	0.64
% BODY FAT	0.91
LT HAND GRIP STR (kg)	0.87
RT HAND GRIP STR (kg)	0.92
LOW BODY STR (kg)	0.76
ARM STR (kg)	0.79

required differing energy expenditures the within subject variation for the 4 tasks was greater than the between duplicate variation. For this reason reliability coefficients were not determined for the energy cost assessment.

ANALYSIS OF DATA

Part A Physical Fitness Appraisal

The mean and standard deviation values of the following variables were calculated: age, height, weight, body surface area, percent body fat, fat free weight, pre-exercise metabolic rate, maximum oxygen uptake, maximum heart rate, time to exhaustion (anaerobic run), maximum recovery oxygen debt, right hand grip strength, left hand grip strength, upper body strength and lower body strength (Table 4 p. 40).

Part B Energy Cost Assessment

The variables analyzed were total task net oxygen uptake, aerobic component (task VO_2), anaerobic component (task debt), task heart rate, task respiratory exchange ratio, and task time.

In order to test the hypotheses of the current study the following statistical procedures were employed:

1. The total task net O_2 uptake measurements during the four work tasks and pre-exercise

were subjected to a one-way analysis of variance to determine if any of the five conditions was significantly different from the others. A post hoc Tukey (a) test (124) was introduced to determine the location of the significance.

2. The aerobic and anaerobic components of Group 1 (< 40 ml·kg^{-1}) and Group 2 (≥ 40 ml·kg^{-1}) were subjected to analyses of variance to determine if the two groups were significantly different from each other.

In an attempt to clarify the net O_2 cost relationships of the four work tasks one-way analyses of variance and post hoc Tukey (a) tests (124) were carried out on the following variables:

1. METS,
2. Task VO_2 (aerobic component),
3. Task Debt (anaerobic component),
4. Task RE,
5. Task HR,
6. Percent contribution of aerobic processes to total net O_2 cost, and
7. Percent contribution of anaerobic processes to total net O_2 cost.

In an attempt to determine whether there was a relationship between various physical measurements of the fire fighters and the work tasks the following analyses were employed:

1. All physical fitness appraisal and energy cost data were analysed by correlation matrix, and
2. The 20 fire fighters who participated in the energy cost assessment (Part B of study) were placed into two groups under each of the following conditions and subjected to a series of multiple one-way analyses of variance.
    a) < 20% body fat and ≥ 20% body fat,
    b) < 110 kg arm strength and ≥ 130 kg arm strength, and
    c) < 200 kg lower body strength and ≥ 250 kg lower body strength.

Data from all procedures were punched on IBM cards and analyzed on an IBM 360-67 computer at the Computing Centre at the University of Windsor.

Method of Presentation of O_2 Cost Data

It is apparent from the literature that the O_2 deficit - recovery O_2 debt relationship is definitely not clear cut. For this reason the O_2 cost data of the 4 fire fighting tasks were presented in three ways:

1. Actual measured total net O_2 cost
2. Calculated total net O_2 cost
    a) assuming a deficit-debt ratio of 1:1.2
    b) assuming a deficit-debt ratio of 1:1.6
    c) assuming a deficit-debt ratio of 1:2.0.
3. Adjusted O_2 cost in litres·min^{-1}.

Based on the kinetics of $\dot{V}O_2$ from rest to work the "steady state" $\dot{V}O_2$ of the four fire fighting tasks can be calculated and expressed in litres·min^{-1}. Since it has been demonstrated (22, 104) that 90-100% of the required $\dot{V}O_2$ was attained during the second minute of exercise two calculations were made for T1:

a) assuming the $\dot{V}O_2$ at 100 seconds was "steady state"

b) assuming the $\dot{V}O_2$ at 100 seconds was 90% of the eventual "steady state".

The "steady state" $\dot{V}O_2$ was calculated in the following way:

T2,T3,T4: (30 second $\dot{V}O_2$) X 2

T1: 1. 100 second $\dot{V}O_2$,

2. (100 second $\dot{V}O_2$) X 10/9.

This method is intended as only an approximation for comparison purposes and not as an exact measure although expressing the results in litres·min^{-1} is advantageous since they may then be more adequately compared with various other occupational tasks or activities.

CHAPTER IV

RESULTS

In this investigation the energy cost of four selected fire fighting tasks and the influence of physical fitness levels on these tasks was the central question to be evaluated. The mean and standard deviation values describing the physical characteristics of the 45 fire fighters grouped into three 10 year age groups (20-29, 30-39 and 40-49) are presented in Table 4 (p. 40) and in Table 5 (p. 41) for the fire fighters who engaged in the respective work tasks. There were no significant differences among the firemen who participated in each of the 4 work tasks and the total sample ($P > 0.05$).

Actual Measured Total Net Oxygen Cost

The mean total net O_2 cost for tasks 1-4 and pre-exercise were 6.23, 3.08, 4.69, 2.10 and 0.361 litres respectively (Table 8 and Figure 12). The kilocalorie equivalents are presented in the same table. A one-way analysis of variance indicated a significant difference among the five conditions at the 0.05 level. The subsequent Tukey (a) procedure revealed that each task was significantly different from each other and

TABLE 8

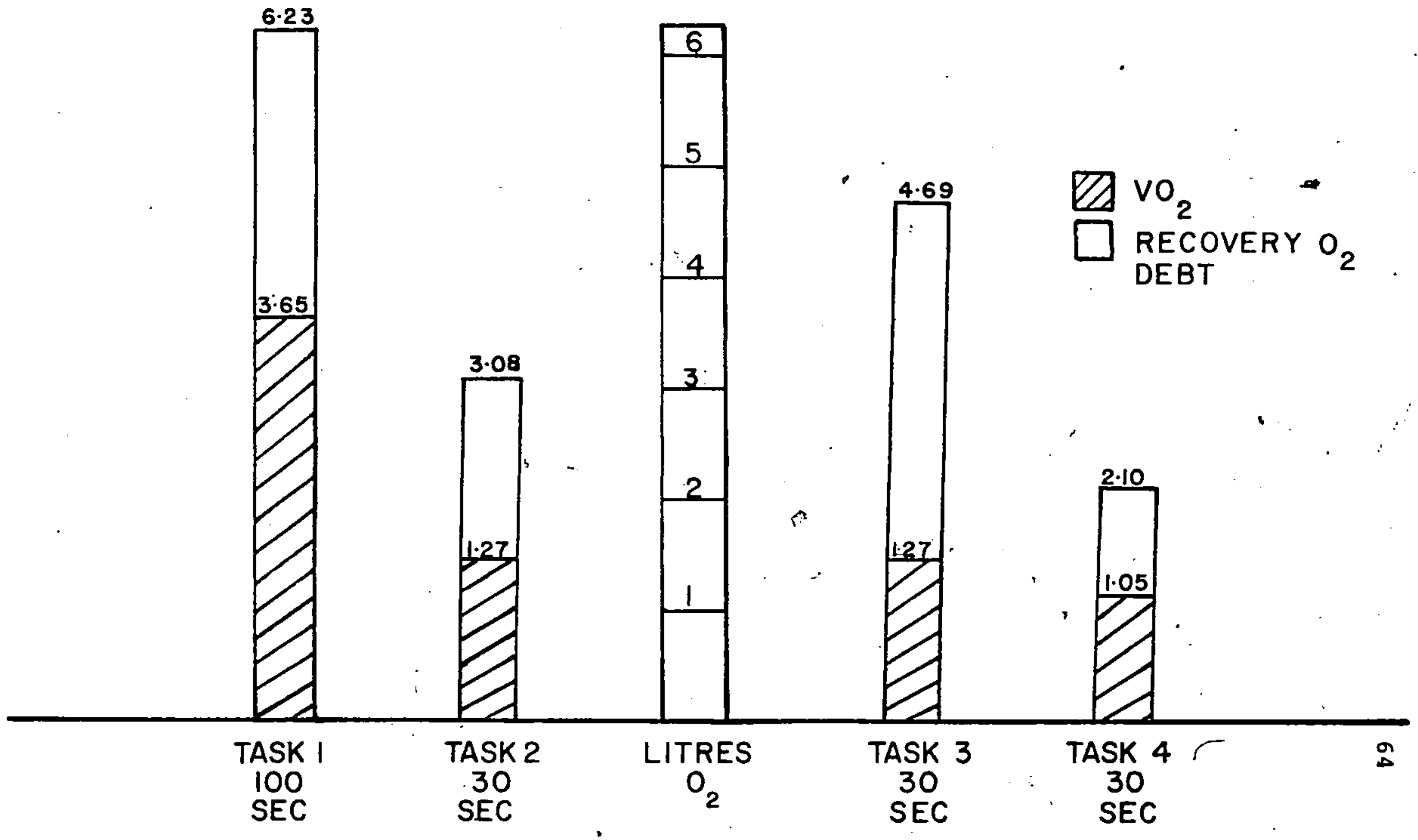
MEAN VALUES DESCRIBING THE ENERGY COST OF TASKS 1-4 AND PRE-EXERCISE (N = 10)

	TOTAL NET O_2	KCAL	METS	AEROBIC (l)	AEROBIC (% of total)	ANAEROBIC (l)	ANAEROBIC (% of total)	RE	HR	TIME (sec)
TASK 1 (Aerial Ladder Climb)	6.23	31.16	24.92	3.65	59.18	2.58	40.82	1.00	156.9	100.41
TASK 2 (Rescue "Victim")	3.08	15.40	12.32	1.27	41.24	1.81	58.76	0.99	133.8	31.63
TASK 3 (Dragging Hose)	4.69	23.47	18.76	1.27	27.06	3.42	72.94	1.07	139.1	29.81
TASK 4 (Ladder Raise)	2.10	10.48	8.40	1.05	51.06	1.04	48.94	0.97	115.1	31.39
PRE-EXERCISE	0.36	1.81	1.44	0.36	100.00	0.00	0.00	0.81	73.3	60.00
$F_{obs}(4,45)$	213.1*	213.1*	213.1*	403.0*	342.8*	120.3*	342.8*	38.7*	141.5*	645.9*

*P < 0.05

FIGURE 12

TOTAL NET ENERGY COST IN LITRES OF O_2



from pre-exercise values at the 0.05 level (see appendix A).

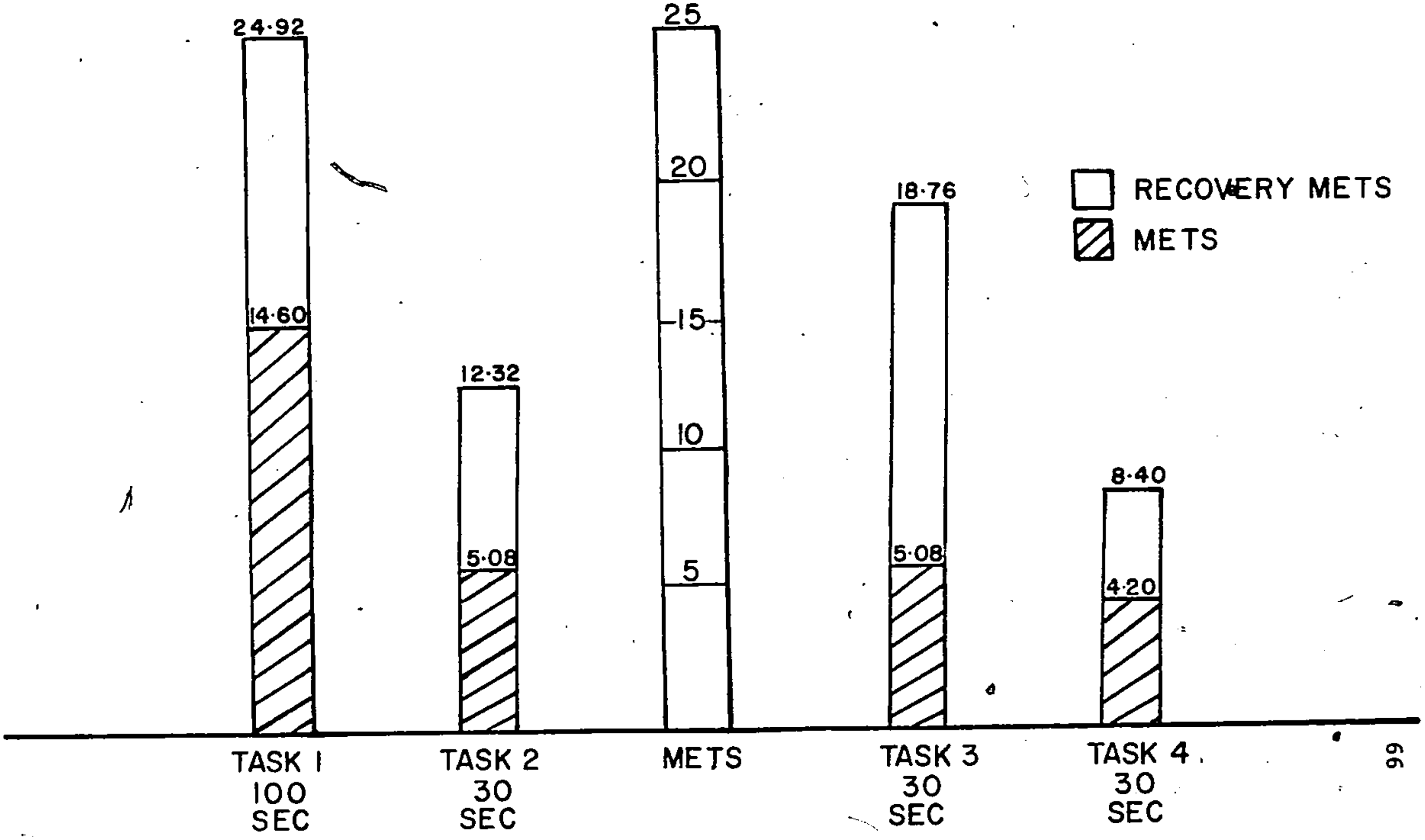
However caution must be employed when comparing T1 to the other four tasks because the duration of the work periods varied (T1 approximately 100 seconds, T2-T4 approximately 30 seconds). Clearly, since T1 required a longer period of time to complete (> than 3X) it could demand a greater total energy cost even if its intensity was lower than the other three tasks. Table 9 represents an attempt to standardize the four tasks so that a more adequate comparison can be made.

Multiples of Resting Rate (METS)

The mean METS for tasks 1-4 and pre-exercise were 24.92, 12.32, 18.76, 8.40 and 1.44 respectively (Table 8 and Figure 13). A one-way analysis of variance indicated a significant difference among the five conditions at the 0.05 level. The subsequent Tukey (a) procedure revealed that each task was significantly different from pre-exercise at the 0.05 level and that each task was significantly different from each other at the same level except task 2 (rescue of 'victim') and task 4 (raising ladder) (see appendix A).

FIGURE 13

TOTAL NET ENERGY COST IN METS



Task VO_2 (Aerobic Component)

The mean task VO_2 for tasks 1-4 and pre-exercise were 3.65, 1.27, 1.27, 1.05 and 0.361 litres respectively (Table 8). A one-way analysis of variance indicated a significant difference among the five conditions at the 0.05 level. The subsequent Tukey (a) procedure revealed that all four tasks were significantly different from pre-exercise and that task 1 (aerial ladder climb) differed significantly from each of the other three tasks at the 0.05 level (see appendix A)

Task O_2 Debt (Anaerobic Component)

The mean task O_2 debt for tasks 1-4 and pre-exercise were 2.58, 1.81, 3.42, 1.04 and 0.00 litres respectively (Table 8). A one-way analysis of variance indicated a significant difference among the five conditions at the 0.05 level. The subsequent Tukey (a) procedure revealed the following significant differences at the 0.05 level: all four tasks from pre-exercise, task 1 and 3 from task 4, and task 3 from task 2 (see appendix A).

Task Respiratory Exchange Ratio (RE)

The mean RE for tasks 1-4 and pre-exercise were 1.00, 0.99, 1.07, 0.97 and 0.81 respectively (Table 8). A one-way analysis of variance indicated a significant difference among the five conditions at the 0.05 level.

TABLE 9

ADJUSTED MEAN VALUES DESCRIBING THE ENERGY COST OF TASKS 1-4

(N=10)

	$l \cdot min^{-1}$	$kcal \cdot min^{-1}$	METS	30 sec HR
TASK 1 (Aerial Ladder Climb)	2.440	12.20[1]	9.76	130
	2.190	10.95[2]	8.76	130
TASK 2 (Rescue "Victim")	2.534	12.67	10.14	133
TASK 3 (Dragging Hose)	2.548	12.74	10.19	139
TASK 4 (Ladder Raise)	2.300	11.50	9.20	115

[1] assuming the $\dot{V}O_2$ at 100 seconds was 90% of the eventual "steady state".

[2] assuming the $\dot{V}O_2$ at 100 seconds was "steady state".

The subsequent Tukey (a) procedure revealed that: each task was significantly different from pre-exercise at the 0.05 level, task 3 was different from task 2 and T4, and T1 was different from T3 at the same level of significance (see appendix A).

Task Heart Rate (HR)

The mean HR for tasks 1-4 and pre-exercise were 159.90, 133.80, 139.10, 115.10 and 73.30 bpm respectively (Table 8). A one-way analysis of variance indicated a significant difference among the five conditions at the 0.05 level. The subsequent Tukey (a) procedure revealed the following significant differences at the 0.05 level: all tasks from pre-exercise, task 1, 2 and 3 from 4 and task 1 from 2 and 3 (see appendix A).

Percent Aerobic

The mean percent contribution of aerobic processes to the net O_2 cost for tasks 1-4 and pre-exercise were 59.18, 41.24, 27.06, 51.06 and 100.00 respectively (Table 8). A one-way analysis of variance indicated a significant different among the five conditions at the 0.05 level. The subsequent Tukey (a) procedure revealed that each task was significantly different from each other and from pre-exercise values at the 0.05 level (see appendix A).

Percent Anaerobic

The mean percent contribution of anaerobic processes to the net O_2 cost for tasks 1-4 and pre-exercise were 40.82, 58.76, 72.94, 48.94 and 0.00

respectively (Table 8). A one-way analysis of variance indicated a significant difference among the five conditions at the 0.05 level. The subsequent Tukey (a) procedure revealed that each task was significantly different from each other and from pre-exercise values at the 0.05 level (see appendix A).

Calculated Total Net O_2 Cost

The calculated mean total O_2 cost and the other values describing tasks 1-4 based on the three deficit-recovery debt ratios are presented in Tables 10-12.

Relationship Between Various Physical Measurements and the Work Tasks

A correlation matrix of selected variables is presented in Table 13.

An analysis of variance between group 1 (< 40 ml·kg^{-1}) and group 2 (≥ 40 ml·kg^{-1}) revealed that the percent contribution of aerobic and anaerobic processes to the total O_2 cost was not significantly different ($P < 0.10 > 0.05$). The mean values were:

	% Aerobic	% Anaerobic
Group 1 (< 40 ml·kg^{-1})	40.16	59.84
Group 2 (≥ 40 ml·kg^{-1})	47.27	52.73

Analysis of variance between:

1. Group 1 (arm strength < 110 kg) and Group 2 (arm strength ≥ 130 kg),
2. Group 1 (lower body strength < 200 kg) and Group 2 (lower body strength ≥ 250 kg),
3. Group 1 (< 20% body fat) and Group 2 (≥ 20% body fat),

failed to detect any significant differences for percent contribution of anaerobic and aerobic processes ($P > 0.05$).

TABLE 10

CALCULATED MEAN VALUES DESCRIBING THE ENERGY COST OF TASKS 1-4
(assuming a deficit-debt ratio of 1:1.2)
(N=10)

	TOTAL NET O_2 (1)	KCAL	METS	AEROBIC		ANAEROBIC		RE	HR	TIME (sec)
				(1)	(% of total)	(1)	(% of total)			
TASK 1 (Aerial Ladder Climb)	5.80	29.01	23.21	3.65	63.45	2.15	35.55	1.00	156.9	100.41
TASK 2 (Rescue "Victim")	2.78	13.89	11.11	1.27	45.68	1.51	54.32	0.99	133.8	31.63
TASK 3 (Dragging Hose)	4.12	20.62	16.49	1.27	30.76	2.85	69.24	1.07	139.1	29.81
TASK 4 (Ladder Raise)	1.92	9.61	7.69	1.05	55.53	0.87	44.47	0.97	115.1	31.39
$F_{obs}(4,45)$	229.6*	229.6*	229.6*	403.0*	300.4*	120.3*	300.4*	38.7*	141.5*	645.9*

*$P < 0.05$

TABLE 11

CALCULATED MEAN VALUES DESCRIBING THE ENERGY COST OF TASKS 1-4
(assuming a deficit-debt ratio of 1:1.6)
(N=10)

	TOTAL NET O_2 (1)	KCAL	METS	AEROBIC (1)	AEROBIC (% of total)	ANAEROBIC (1)	ANAEROBIC (% of total	RE	HR	TIME (sec)
TASK 1 (Aerial Ladder Climb)	5.27	26.33	21.06	3.65	69.77	1.61	30.23	1.00	156.9	100.41
TASK 2 (Rescue "Victim")	2.40	12.00	9.60	1.27	52.81	1.13	47.19	0.99	133.8	31.63
TASK 3 (Dragging Hose)	3.41	17.05	13.64	1.27	37.13	2.14	62.87	1.07	139.1	29.81
TASK 4 (Ladder Raise)	1.71	8.53	6.82	1.05	62.39	0.65	37.61	0.97	115.1	31.39
F_{obs} (4,45)	258.2*	258.2*	258.2*	403.0*	248.6*	120.3*	248.6*	38.7*	141.5*	645.9*

*P < 0.05

TABLE 12

CALCULATED MEAN VALUES DESCRIBING THE ENERGY COST OF TASKS 1-4
(assuming a deficit-debt ratio of 1:2.0)
(N=10)

	TOTAL NET O_2 (l)	KCAL	METS	AEROBIC		ANAEROBIC		RE	HR	TIME (sec)
				(l)	(% of total)	(l)	(% of total)			
TASK 1 (Aerial Ladder Climb)	4.94	24.72	19.76	3.65	74.22	1.29	25.78	1.00	156.9	100.41
TASK 2 (Rescue "Victim")	2.17	10.87	8.68	1.27	58.27	0.91	41.73	0.99	133.8	31.63
TASK 3 (Dragging Hose)	2.98	14.92	11.92	1.27	42.40	1.71	57.60	1.07	139.1	29.81
TASK 4 (Ladder Raise)	1.58	7.88	6.28	1.05	67.40	0.53	32.60	0.97	115.1	31.39
$F_{obs}(4,45)$	281.1*	281.1*	281.1*	403.0*	217.3*	120.3*	217.3*	38.7*	141.5*	645.9*

$*P < 0.05$

TABLE 13

CORRELATION MATRIX OF SELECTED VARIABLES

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1.	$M\dot{V}O_2$ (l)	1.0	.83	.84	-.56	.38	.40	.21	.13	-.11	.22	.49	.36
2.	$M\dot{V}O_2$ ($ml \cdot kg^{-1}$)		1.00	.96	-.59	.61	.67	.35	-.04	-.02	.11	-.07	-.56
3.	$M\dot{V}O_2$ ($ml \cdot 1kg^{-1}$)			1.00	-.58	.59	.68	.34	-.01	-.02	.42	.02	-.21
4.	AGE (yrs)				1.00	-.43	-.42	-.63	-.06	-.04	-.09	-.14	-.10
5.	MAX HR (bpm)					1.00	-.08	-.03	-.52	.08	.11	-.24	-.29
6.	ARM STR (kg)						1.00	.56	.16	-.09	.14	.47	.38
7.	LOW BODY STR (kg)							1.00	.01	-.04	-.20	.11	.23
8.	MAX DEBT (l)								1.00	.86	-.72	.30	.24
9.	MAX DEBT ($ml \cdot kg^{-1}$)									1.00	-.01	-.16	-.15
10.	% BODY FAT										1.00	.23	-.34
11.	WEIGHT (kg)											1.00	.61
12.	FFWT (kg)												1.00

TABLE 13 cont.

CORRELATION MATRIX OF SELECTED VARIABLES

	$\dot{M}VO_2$ $(ml \cdot kg^{-1})$	% FAT	WT (kg)	FFWT (kg)	ARM STR (kg)	LOW BODY STR (kg)
T1 NET O_2		.08	.84	.80		
T2 NET O_2		-.63	.17	.52		
T3 NET O_2		.47	.89	.67		
T4 NET O_2		-.55	.54	.82		
T1 VO_2	.51				.65	.59
T2 VO_2	.66				.59	.46
T3 VO_2	.79				.39	.52
T4 VO_2	.48				.15	-.14
T1 O_2 DEBT	-.55					
T2 O_2 DEBT	-.60					
T3 O_2 DEBT	-.62					
T4 O_2 DEBT	-.51					

CHAPTER V

DISCUSSION

From the results of the present study it is apparent that the four tasks required different energy expenditures and that possibly some of the physical parameters measured may influence the work tasks or the mechanisms which a fireman uses to meet the energy requirements.

Assessment of Total Energy Cost

The assessment of energy cost and more specifically measurement of total net O_2 cost (aerobic + anaerobic components), HR and RE would appear to be a satisfactory method of determining the relative amount of physiological effort demanded by a particular piece of work. The rationale for this statement is as follows:

It is well established that the O_2 cost of a work task increases with the intensity of the work load (6). Whether an individual is able to meet the O_2 demand and therefore complete the particular piece of work is determined by the following factors:

1. the relationship of a given absolute work level to the $M\dot{V}O_2$ of the subject,

2. the duration of the work period,
3. the type of work, and
4. the environmental conditions.

During the first few minutes of work, if it is of light to moderate intensity, an individual's $\dot{V}O_2$ (aerobic component) increases to a "steady state" condition until the $\dot{V}O_2$ is almost equal to the O_2 requirements of the tissues. When this asymptote occurs HR, cardiac output and ventilation have also reached asymptotic levels (6). Since the O_2 supply to the tissues is sufficient there is no accumulation of lactic acid (below 50-80% $M\dot{V}O_2$) and the work can be continued without undue stress for prolonged periods of time (6, 42, 108). By definition therefore, any task which is performed at a constant rate for extended periods of time (i.e., 6 minutes to several hours) is "steady state" work. The O_2 cost of this type of work may be determined by collecting a sample of expired gas, while the work is being performed and calculating the subject's O_2 utilization. Generally the units of measurement of this O_2 utilization are:

1. $\ell \cdot min^{-1}$,
2. $ml \cdot kg^{-1} \cdot min^{-1}$,
3. $ml \cdot lean\ kg^{-1} \cdot min^{-1}$,
4. $kcal \cdot min^{-1}$,

5. METS, and
6. % of $M\dot{V}O_2$.

The value of $\dot{V}O_2$ as a measure of the energy cost of a work task therefore rests on the assumption that $\dot{V}O_2$ represents the total energy expenditure involved. However, $\dot{V}O_2$ reflects only the energy supplied through the aerobic processes. There is in addition to this pathway two anaerobic pathways which also are capable of providing energy for work (lactacid and alactacid energy sources).

It is important to note that even during a "steady state" work task there is an anaerobic contribution to the energy expenditure at the beginning of the work. The cardio-respiratory system's response to work is sluggish at first and "steady state" is not attained for several minutes (6, 42), if at all. During the "circulatory lag" the energy requirement is covered largely by alactic sources which must be repaid at a later time. These alactic sources are presumably replenished after the work is over. In general this occurs through increased $\dot{V}O_2$ during the recovery phase of the task. This portion of supplied energy is not included in the "steady state" work O_2 cost calculations because the $\dot{V}O_2$ is expressed per minute and then multiplied by the length of the task (i.e., as if "steady state" was attained immediately when the work was initiated).

When "steady state" is not attained during work due to intensity and/or duration this anaerobic portion must be calculated if a determination of total O_2 cost is to be attempted. If the work is severe (> 50-80% $M\dot{V}O_2$ depending on level of training) and is prolonged after the alactic sources are exhausted lactic sources come more and more into play to cover the discrepancy between the $\dot{V}O_2$ and the actual O_2 cost (118). The lactic component is present but negligible until the alactic sources are depleted (51). Severe work where the O_2 deficit is large cannot be continued for very long because the accumulation of the end products of anaerobic metabolism and the associated discomfort cause the subject's muscles to cease functioning (6). The total O_2 cost calculation then becomes somewhat more complicated because the contribution of the anaerobic processes must be determined as well as the aerobic. Clearly, measurement of the aerobic processes of an individual performing severe work provides only a portion of the total O_2 cost. In addition the O_2 stores within the body (blood, myoglogin, etc.) plus the glycolgen to lactate energy yielding processes must be determined. Since both of these sources are "borrowed" they must presumably be paid back when the work is completed. Since there is evidence (61) to suggest that lactate can be metabolized during work predictions of the anaerobic cost from blood lactate measurements during recovery may be misleading.

O_2 Deficit - Recovery O_2 Debt Relationship

The work tasks of the present study because of their intensity and duration were clearly not "steady state" and therefore in order to determine the total O_2 cost it was necessary to include a measurement of the anaerobic contribution to the energy supply. A recovery O_2 debt collection period of 6 minutes was employed for determination of the anaerobic component for the following reasons:

1. A pilot study revealed that a 6 minute recovery O_2 debt collection following a maximal workbout that produced volitional fatigue in 60-100 seconds was representative of a 15 minute debt. It was felt that this relationship existed because the O_2 deficit during this work was covered largely by alactic sources. The 6 minute collection period was sufficient to cover the alactic component and also the minimal contribution of the lactic component. Since the intensity of the respective fire fighting tasks was not as great as this laboratory task it was assumed that the 6 minute collection period was valid. As a check to determine if the 6 minute debt

collection actually represented the total debt incurred after the fire fighting tasks, the 6th minute of recovery $\dot{V}O_2$ was partitioned from the other 5 minutes with two subjects in the longest task (T1 Aerial Ladder Climb) and the most strenuous task (T3 Dragging Hose). In both cases there was no significant difference ($P > 0.05$) between pre-exercise $\dot{V}O_2$ and the 6th minute of recovery. These data were taken as evidence that 6 minute recovery O_2 debt collections were adequate for determining the total recovery O_2 debt of work tasks of such short duration. Whether the observed relationship of 6 minute recovery debt to 15 minute debt exists at other intensities or durations of work periods is not known, however as the lactic component becomes more involved it is suspected that longer debt collections would be necessary. It is important to point out however, that the practice of prolonged debt collections may cloud the issue more than clarify it because as the debt collection period is extended the contribution of "increased resting metabolism" to the measured recovery O_2 debt becomes greater. For this reason, if this large "grey area" can be minimized, as it probably is with short work tasks, then a more accurate determination of the anaerobic component can be made.

2. Brooks (17) quantified the alactic energy sources available during exercise. His theoretical value of 2.99 litres agrees with other investigators (81, 113, 119). Since the mean recovery O_2 debts in this study ranged from 1.04 to 3.42 litres and it has been demonstrated that alactic sources are more important during work of short duration (25, 55, 56, 62, 74, 83, 120) it appears that the anaerobic contribution to the energy cost of these tasks was largely alactic. Since anaerobic glycolysis probably played an insignificant role in these fire fighting tasks and because the validity of blood lactate values is questionable it was decided that measurement of blood lactate would not provide any additional information and for this reason was not measured.

An attempt was made to measure body temperature changes during the actual fire fighting tasks involved in this study by monitoring surface temperature changes in order to determine the magnitude of the Q_{10} effect. However, it was concluded that this method was too indirect to be of value (no consistent results were obtained). Since rectal temperature was the only available method of measuring deep body temperature no measurement was attempted because it was felt that the tasks were not of sufficient duration for a change to be detected (112). Deep muscle temperature determination would have provided valuable insight into the body temperature changes however, internal muscle thermocouples were not available. Although the temperature effect during recovery was not determined it was assumed to have little effect on the $\dot{V}O_2$ because of the duration of the work tasks.

Method of Presentation of O_2 Cost Data

Method #1 (actual total net O_2 cost) provided a consistent measure of the O_2 required by any man who completed the work tasks (regardless of the factors contributing to the measured recovery O_2 debt). If there are individual differences in the O_2 deficit-recovery O_2 debt (47), this method eliminates this source of error. The difficulty with this method arises when the O_2 cost of this type of work is compared with other work tasks (i.e., "steady state") reported in the literature. Since the measured recovery O_2 debt was greater than the O_2 deficit by an undetermined amount "non-steady state" work tasks appear more strenuous than they actually are.

Method #2 (calculated total net O_2 cost) represents an attempt to equate the measured recovery O_2 debt with the actual O_2 deficit by employing a range of deficit-debt ratios (1:1.2 - 1:2.0) from the literature. Assuming that this range of ratios is accurate this procedure enables comparisons between "non-steady state" and "steady state" work provided the work tasks are of the same duration. Since the O_2 cost is expressed as a total and not a rate it is difficult to determine whether the O_2 cost was higher in longer tasks (i.e., aerial ladder climb) because of the intensity or simply because the $\dot{V}O_2$ was collected over a longer period of time.

Method #3 (adjusted O_2 cost) represents another attempt to assess the 4 work tasks in terms of "steady state" work. This procedure has an added advantage since it expresses the O_2 cost as a rate (litres·min^{-1}). It therefore makes a more meaningful comparison between the longest task (aerial ladder climb) and each of the other three tasks. Assuming that this procedure provides an accurate representation of the "actual steady state" $\dot{V}O_2$ it is probably the best method.

It must be kept in mind however that methods #2 and 3 represent only approximations of the actual cost and therefore are subject to considerable error. For this reason, method #1 must be considered the best method since it represents the total O_2 required to complete the work task. It has been suggested that calculations of energy cost employing recovery O_2 debt determinations are erroneous because the elevated recovery $\dot{V}O_2$ is due not only to the O_2 deficit created during the work but also to some consequences of work which are still present during recovery, i.e., Q_{10} effect, ventilation and cardiac costs, etc. It might well be argued that if these occur as a result of the work then they are required in order to complete the task and therefore should be considered in the determination of the total energy cost. Perhaps work tasks which require a considerable anaerobic component may have to be described in different units than those utilized routinely when describing "steady state" work.

RE

The use of RE as a measure of energy cost must be employed with caution because:

1. the entire range of RE during exercise is small,
2. RE in maximum work can vary greatly between individuals,
3. other factors affect RE such as diet and level of training, and
4. during short work periods where lactate is not formed RE is not representative of severity.

These factors make results difficult to assess in some cases. It appears that the use of RE as a measure of energy expenditure provides only an indication of severity and that precise determinations are difficult if RE is the only information available.

HR

Heart rate as an indication of energy expenditure has been employed adequately in many studies (4, 18, 14). In this investigation however, the value of HR is reduced for two reasons:

1. the work is "non-steady state", and
2. the duration of the work is varied.

Even during "non-steady state" work HR still provides useful information regarding the intensity of the work although accurate assessment of the $\dot{V}O_2$ is difficult. However when the work periods vary, as is the case of T1 in relation to T2-T4, HR response may be misleading. For example, based on HR responses the severity of the four fire fighting tasks would be as follows:

1.	Task 1	Aerial Ladder Climb	156.9
2.	Task 3	Dragging Hose	139.1
3.	Task 2	Rescue of "Victim"	133.8
4.	Task 4	Ladder Raise	115.1

The difference between T3 and T2 was not significant. The HR response of T1 is probably approaching "steady-state" since this task lasted 100 seconds while the other three tasks are definitely far from "steady state". Undoubtedly, if T2-T4 were prolonged to 100 seconds their HR responses would be much higher. It is interesting to note that the 30 second heart rate for tasks 1, 2 and 3 was virtually the same (table 9). This 30 second HR response may however be characteristic of any submaximal task. It appears that during "non-steady state" work of varying duration HR response as an indicator of energy cost must be viewed with caution.

Correlation Between Selected Variables

The correlation coefficients of -.56, -.43, -.42 and -.63 between age and $\dot{M}VO_2$, age and maximal HR, age and arm strength and age and lower body strength are not unusual as the decreases with age of $\dot{M}VO_2$, maximal HR and muscular strength are well documented (6, 42).

The correlation between $\dot{M}VO_2$ ($ml \cdot kg^{-1}$) and lower body strength ($r = .67$) was greater than between $\dot{M}VO_2$ ($ml \cdot kg^{-1}$) and arm strength ($r = .35$). However, these correlations may be explained at least partially by the age range of the subjects. The younger subjects on the average were stronger and had higher $\dot{M}VO_2$'s than the older men. $\dot{M}VO_2$ was also positively correlated .51, .66, .79, and .48 with task $\dot{V}O_2$ (aerobic component) of tasks 1-4 respectively and negatively correlated with task debt (anaerobic component) -.55, -.66, -.62 and -.51.

These findings suggested as has been indicated by others (36, 121) that individuals with higher $\dot{M}VO_2$'s are able to supply a greater percentage of the total O_2 cost of an activity aerobically and therefore require a smaller percentage anaerobically.

An analysis of variance between Group 1 (< 40 $ml \cdot kg^{-1}$) and Group 2 (> 40 $ml \cdot kg^{-1}$) may support this suggestion however only a trend was observed ($P < 0.10 > 0.05$). If this is in fact the case, it would be especially important to firemen because actual fire fighting does not consist of completion of one 30 second task. Instead, it may require hours of work during which time intermittent demands of severe energy expenditure are required. Therefore, an individual who is able to provide a greater percentage of O_2 aerobically can be expected to work longer at the same intensity or work more strenuously for the same period of time than his less fortunate counterpart. The advantages of this phenomenon in a demanding life-threatening situation, such as fire fighting, are obvious. In addition, it is probable that the percent contribution of aerobic processes would be even more marked than in the present study if:

1. the groups selected had greater variability, i.e., < 25 $ml \cdot kg^{-1}$ and > 50 $ml \cdot kg^{-1}$. The range of $\dot{M}VO_2$'s of the firemen sampled prevented such a comparison.

2. the work tasks employed were of longer duration. Cunningham (32) observed little difference in $\dot{V}O_2$ during the first 30 seconds of an anaerobic run which produced volitional fatigue in approximately 30-80 seconds before and after a training program designed to improve both aerobic and anaerobic capacity. However, there was a significant increase in $\dot{V}O_2$ between 30 and 80 seconds, demonstrating a greater percentage of aerobically supplied O_2.

Age was negatively correlated with percent contribution of aerobic processes -.38, -.49 and -.82 for tasks 1-3 respectively and positively correlated with percent anaerobic contribution .38, .49 and .82. The above strength and age correlations to aerobic and anaerobic components are interesting however, their interpretation is difficult because of the interrelationship of $M\dot{V}O_2$, age and strength. Little or no decrease in hand grip strength was observed in this sample of fire fighters with advancing age. Although contrary to most previous reports this finding is in agreement with the recent studies of Shock (110) and Petrofsky (98).

Body weight was positively correlated with total net O_2 cost .84, .17, .89 and .54 of tasks 1-4 respectively. This observation is in agreement with many studies which have demonstrated a linear relationship between body weight and $\dot{V}O_2$ (16, 49, 50). The somewhat low correlation of task 2 (rescue of "victim") is probably affected by carriage of the 34 kg dummy. Goldman (50) demonstrated that the metabolic cost of carrying normal loads (up to 30 kg) is the same as carrying an equivalent additional weight of the body itself. Therefore, he concludes that it is possible to combine the body's own weight and the weight of the external load (up to 30 kg) and relate the metabolic rate to the total weight of the loaded individual. When 34 kg was added to the body weight of task 2 the correlation between body weight and total net O_2 was .43. The equipment that the men wore was added to their body weight for all other calculations.

Fat-free weight was also positively correlated with total net O_2 cost .80, .52, .67 and .82 for tasks 1-4 respectively. There appeared to be no consistent correlation between percent fat and total net O_2 cost indicating that the total weight carried was the important criterion and not the percent fat. It is important to note however, that by decreasing % body fat without altering the fat-free weight one can reduce total body weight and thereby decrease the energy cost of any task where the body weight has to carried, i.e., walking, running, climbing, etc.

A noteworthy observation was the lack of correlation between percent body fat and age (-.09). This finding could be interpreted as indicating optimistically that:

1. the older firemen had less body fat than has been reported by others of the same age range (87, 93),
2. perhaps more realistically after comparing the data that the younger firemen were on the average as fat as the older ones, or
3. that the sample was not representative of an "average" adult male population with a distribution of ages.

It appears that weight control is a problem for the younger men as well as the older ones.

The observation of no correlation between $M\dot{V}O_2$ (litres) and maximal recovery O_2 debt (.13), $M\dot{V}O_2$ ($ml \cdot kg^{-1}$) and maximal O_2 debt (-.04) and $M\dot{V}O_2$ ($ml \cdot kg^{-1}$) and maximal O_2 debt $ml \cdot kg^{-1}$ (-.02) is in agreement with others (6, 57, 90). It appears that these two capacities although interrelated are increased by different training procedures (6, 32, 127) and that a high capacity in one does not imply a high capacity in the other. The high correlation between $M\dot{V}O_2$ $ml \cdot kg^{-1}$ and $M\dot{V}O_2$ $ml \cdot lean\ kg^{-1}$ (.96) indicates that there is little justification for relating $\dot{M}VO_2$ to lean body weight as has been done recently and that the more common practice of expressing $\dot{M}VO_2$ in $ml \cdot kg^{-1}$ is sufficient. A recent study by Gitin (48) found that $\dot{M}VO_2$ $ml \cdot kg^{-1}$ provided a more accurate measure and that $\dot{M}VO_2$ when related to lean body weight could be misleading. When relating $\dot{M}VO_2$ to lean body weight it is assumed that adipose tissue does not:

1. interfere with delivery of O_2 to the muscle tissue, and
2. consume an appreciable percentage of the $\dot{V}O_2$.

If one or both of these assumptions are incorrect this measure may give inappropriately high values for obese individuals. It appears that the use of $\dot{M}VO_2$ $ml \cdot kg^{-1}$ is preferable.

The Hypotheses

With respect to the results observed, the following conclusions regarding the original hypotheses are justified:

1. Hypothesis #1 is rejected since each work task was significantly different from the others and from pre-exercise values ($P < 0.05$). In its stead, the alternative H_1: $a_1 \neq a_2 \neq a_3 \neq a_4 \neq a_5$ is accepted.

2. Due to the lack of a significant difference ($P < 0.10 > 0.05$) between Group 1 (< 40 ml·kg^{-1}) and Group 2 (≥ 40 ml·kg^{-1}) the author was unable to reject hypothesis #2.
3. Due to the lack of a significant difference ($P < 0.10 > 0.05$) between Group 1 (< 40 ml·kg^{-1}) and Group 2 (≥ 40 ml·kg^{-1}) the author was unable to reject hypothesis #3.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to evaluate the energy cost of four selected fire fighting tasks and the physical fitness level of professional fire fighters in order to assess the need for a physical fitness program. It was hypothesized that the four work tasks would not differ significantly in energy cost from each other or from pre-exercise values and that $M\dot{V}O_2$ would not be related to the percent contribution of the aerobic and anaerobic components of the various tasks. To test these hypotheses 45 randomly selected professional fire fighters underwent a physical fitness appraisal and 20 of these men engaged in the four selected work tasks at constant pre-determined work rates.

The results indicated that:

1. the four tasks required differing energy expenditures. The differences were presented in three ways:
   (1) total net O_2 cost
   (2) calculated total net O_2 cost
      a) assuming a deficit-debt ratio of 1:1.2
      b) assuming a deficit-debt ratio of 1:1.6
      c) assuming a deficit-debt ratio of 1:2.0

(3) adjusted O_2 cost in litres·min^{-1}.

Based on the present evidence method #1 must be considered the best method, however, method #3 appears promising depending on the magnitude of error involved with this prediction.

2. HR is not a very precise measure of energy cost during "non-steady state" work tasks which are of varying durations and therefore studies which make assumptions concerning energy cost based only on HR responses must be interpreted with caution.
3. RE must be regarded as only an indicator of energy mechanisms and not an exact measure.
4. total body weight was directly related to energy expenditure and percent body fat was only of secondary importance.
5. factors such as arm strength and lower body strength may be related to:
    a) the percent contribution of aerobic processes, and
    b) the total net O_2 cost as indicated by several significant correlations.

   This cannot be determined for certain from the sample studied because of the compounding of this relationship by other factors, such as age and $\dot{M}VO_2$.

6. arm strength, lower body strength, $M\dot{V}O_2$, maximal HR, maximal recovery O_2 debt and time to exhaustion were age related but percent body fat and hand grip strength were not.
7. maximal recovery O_2 debt (6 minutes) was not correlated with $M\dot{V}O_2$.
8. although not significant there was a trend ($P < 0.10 > 0.05$) which may suggest that the higher the $M\dot{V}O_2$ ($ml \cdot kg^{-1}$) the greater the percent contribution of aerobic processes to the total net O_2 cost and therefore the smaller the percent contribution of anaerobic processes.

General Conclusions

In view of the above energy cost results it appears justifiable to conclude that fire fighting consists of heavy physical work. However, since the most strenuous fire fighting tasks were studied (115) it must be concluded that the treadmill task (9 mph, 30% grade) utilized by Barnard (11) to simulate the work stress of fire fighting was too severe. Still, it must be kept in mind that the present investigation utilized isolated work tasks which created a somewhat unrealistic situation. During actual fire fighting conditions other factors such as: 1) environment, 2) emotional stress, and 3) the effects of previous work, in some combination probably increase the amount of stress placed on a fire fighter. It is quite probable that work of this type is associated with massive discharges of catecholamines which could be a factor in the prevalence of CHD in firemen. In addition, it is not surprising to find such a high number of on-the-job injuries considering the intensity of these tasks and the conditions under which they are completed. Closer examination of the injuries received reveals one major type of injury far in excess of all others (sprains and strains).

It would appear therefore that a physical fitness program designed individually for fire fighters and specific to the tasks involved in fire fighting might be advantageous for the following reasons:

1. aerobic training will reduce body weight (if diet is constant) therefore resulting in a decreased energy cost of all work tasks where the body must be lifted or carried.
2. strength training results in increased muscular strength which may increase the percent contribution of aerobic processes to the total net O_2 cost and therefore decrease the percent anaerobic contribution.
3. strength training will help prevent sprains and strains by strengthening muscles, bones, ligaments and tendons.

4. increased fitness results in: a) no change in plasma catecholamines, or b) a reduced response in urinary catecholamines when exposed to a hazardous task or a stressful situation, which may decrease the incidence of CHD.
5. aerobic training results in an increase in $\dot{M}VO_2$ which may promote a greater percentage aerobic contribution to the total net O_2 cost and therefore a lesser anaerobic contribution. This means that a fire fighter who is "more fit" may be able to work longer or more strenuously during the same type of work than his "less fit" counterpart.

Recommendations for Further Research

It is apparent that the precise assessment of the energy cost of "non-steady state" work is much more difficult and subject to considerably more variance than is "steady state" work. When the tasks are of varying durations the difficulty is further increased. The following recommendations are presented in the hope that future research may eventually devise a method of utilizing some measure to determine the anaerobic component so that the energy cost of "non-steady state" work can be compared accurately with the current literature on "steady state" work.

1. accurate quantification and confirmation of the various contributing factors to total measured recovery O_2 debt.
2. definition and quantification of the 3rd component of recovery O_2 debt and its importance to work tasks of varying durations (especially very short work periods).
3. confirmation of the O_2 deficit - recovery O_2 debt ratios of the three components previously reported (99) and the importance of each to varying durations of work.
4. establishment and justification of standardized debt collection periods.
5. precise determination of the error involved when predicting the eventual "steady state" $\dot{V}O_2$ from the 30 second $\dot{V}O_2$.

In addition, the following recommendations are presented with respect to research relating specifically to fire fighters and the energy cost of fire fighting:

1. determination of similar measures at fires in order to partition the added stress of actual fire fighting from the cost of the isolated work tasks. In order to provide a more accurate assessment the following additional measures should be taken if possible,

a) respiratory rate, b) muscle and core temperature changes, c) muscle lactates, and d) blood catecholamines.

2. more detailed study of the effects of muscular strength on MVO_2 during both static and dynamic work (especially with work that requires greater than 60 percent maximal voluntary contraction).

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APPENDIX A

SIGNIFICANT F VALUES WITH ONE-WAY ANALYSIS OF VARIANCE AND TUKEY'S (a) TEST

Energy Cost Assessment

a) Actual Measured Total Net O_2 Cost
Analysis of Variance for Total
Net O_2 Cost

Source of Variation	df	SS	MS	F
Group	4	206.729	51.582	213.118*
Error	45	10.913	0.243	
Total	49	217.642		

$*P < 0.05$

Tukey (a) Test for Total Net O_2

Tukey's (a) score = q.95 (5,45) = 6.268

Conditions	T5 3.61	T4 20.96	T2 30.79	T3 46.93	T1 62.32
T5 Pre-exercise 3.61		17.35*	27.18*	43.32*	58.71*
T4 Raise Ladder 20.96		-	9.83*	22.36*	41.36*
T2 Rescue "Victim" 30.79			-	16.14*	31.53*
T3 Drag Hose 46.93				-	15.39*
T1 Ladder Climb 62.32					-

$*P < 0.05$

Analysis of Variance for METS

Source of Variation	df	SS	MS	F
Group	4	1784.917	446.229	141.802*
Error	45	141.609	3.147	
Total	49	1926.526		

*$P < 0.05$

Tukey (a) Test for METS

Tukey's (a) score = q.95 (5,45) = 22.579

Conditions	T5 10.00	T4 59.54	T2 84.72	T3 134.18	T1 182.91
T5 Pre-exercise 10.00	-	49.54*	74.72*	124.18*	172.91*
T4 Raise Ladder 59.54		-	25.18*	74.64*	123.37*
T2 Rescue "Victim" 84.72			-	49.46*	98.19*
T3 Drag Hose 134.18				-	48.73*
T1 Ladder Climb 182.91					-

*$P < 0.05$

Analysis of Variance of Task VO_2 (aerobic component)

Source of Variation	df	SS	MS	F
Group	4	62.389	15.597	402.956*
Error	45	1.742	0.039	
Total	49	62.131		

*$P < 0.05$

Tukey (a) Test for Task VO_2 (aerobic component)

Tukey's (a) score = q.95 (5,45) = 2.504

Conditions	T5 3.61	T4 10.54	T2 12.67	T3 12.74	T1 36.54
T5 Pre-exercise 3.61		6.93*	9.06*	9.13*	32.93*
T4 Raise Ladder 10.54		-	2.13	2.20	26.00*
T2 Rescue "Victim" 12.67			-	0.07	23.87*
T3 Drag Hose 12.74				-	23.80*
T1 Ladder Climb 36.54					-

*$P < 0.05$

Analysis of Variance for Percent Aerobic

Source of Variation	df	SS	MS	F
Group	4	30255.324	7563.831	342.839*
Error	45	922.807	22.062	
Total	49	31248.131		

*$P < 0.05$

Tukey (a) Test for Percent Aerobic

Tukey's (a) score = q.95 (5,45) = 59.785

Conditions	T3	T2	T4	T1	T5
	270.60	412.36	510.62	591.76	1000.00
T3 Drag Hose 270.60	-	141.76*	240.02*	321.16*	729.40*
T2 Rescue "Victim" 412.36		-	98.26*	179.40*	587.64*
T4 Raise Ladder 510.62			-	81.14*	489.38*
T1 Ladder Climb 591.76				-	408.24*
T5 Pre-exercise 1000.00					-

*$P < 0.05$

Analysis of Variance for Maximum 6 Minute Recovery O_2 Debt

Source of Variation	df	SS	MS	F
Group	4	70.367	17.592	120.251*
Error	45	6.583	0.146	
Total	49	76.950		

*$P < 0.05$

Tukey (a) Test for Maximum 6 Minute Recovery O_2 Debt

Tukey's (a) score = q.95 (5,45) = 5.527

Conditions	T5	T4	T2	T1	T3
	0.00	10.42	18.12	25.78	34.19
T5 Pre-exercise 0.00	-	10.42*	18.12*	25.78*	34.19*
T4 Raise Ladder 10.42		-	7.70*	15.36*	23.77*
T2 Rescue "Victim" 18.12			-	7.66*	16.07*
T1 Ladder Climb 25.78				-	8.41*
T3 Drag Hose 34.19					-

*$P < 0.05$

Analysis of Variance for Percent Anaerobic

Source of Variation	df	SS	MS	F
Group	4	30255.324	7563.831	342.839*
Error	45	922.807	22.062	
Total	49	31248.131		

*P < 0.05

Tukey (a) Test for Percent Anaerobic

Tukey's (a) score = q.95 (5,45) = 72.82

Conditions	T5 0.00	T1 408.24	T4 489.38	T2 587.64	T3 729.40
T5 Pre-exercise 0.00	-	408.24*	489.38*	587.64*	729.40*
T1 Ladder Climb 408.24		-	81.14*	179.40*	321.16*
T4 Raise Ladder 489.38			-	98.26*	240.02*
T2 Rescue "Victim" 587.64				-	141.76*
T3 Drag Hose 729.40					-

*P < 0.05

Analysis of Variance for RE

Source of Variation	df	SS	MS	F
Group	4	0.353	0.088	38.659*
Error	45	0.103	0.002	
Total	49	0.456		

*P < 0.05

Tukey (a) Test for RE

Tukey's (a) score = q.95 (5,45) = 0.61

Conditions	T5 8.12	T4 9.68	T2 9.87	T1 10.00	T3 10.66
T5 Pre-exercise 8.12	-	1.56*	1.75*	1.88*	2.54*
T4 Raise Ladder 9.68		-	0.19	0.32	0.98*
T2 Rescue "Victim" 9.87			-	0.13	0.79*
T1 Ladder Climb 10.00				-	0.66*
T3 Drag Hose 10.66					-

*P < 0.05

Analysis of Variance for HR

Source of Variation	df	SS	MS	F
Group	4	40555.120	10138.780	141.498*
Error	45	3224.400	71.653	
Total	49	43779.520		

*P < 0.05

Tukey (a) Test for HR

Tukey's (a) score = q.95 (5,45) = 107.74

Conditions	T5 733	T4 1151	T2 1338	T3 1391	T1 1569
T5 Pre-exercise 733	-	418*	605*	658*	836*
T4 Raise Ladder 1151		-	187*	240*	418*
T2 Rescue "Victim" 1338			-	53	231*
T3 Drag Hose 1391				-	178*
T1 Ladder Climb 1569					-

*P < 0.05

b) Calculated Total Net O_2 Cost
i) Deficit-debt ratio 1:2.0

Analysis of Variance for Total Net O_2 Cost

Source of Variation	df	SS	MS	F
Group	4	116.967	29.242	281.081*
Error	45	4.682	0.104	
Total	49	121.649		

*P < 0.05

Analysis of Variance for METS

Source of Variation	df	SS	MS	F
Group	4	1020.156	255.039	178.608*
Error	45	64.257	1.428	
Total	49	1084.413		

*P < 0.05

Analysis of Variance for Task VO_2 (aerobic component)

Source of Variation	df	SS	MS	F
Group	4	62.389	15.597	402.955*
Error	45	1.742	0.039	
Total	49	64.131		

$*P < 0.05$

Analysis of Variance for Percent Aerobic

Source of Variation	df	SS	MS	F
Group	4	18120.452	4530.113	217.270*
Error	45	938.255	20.850	
Total	49	19058.708		

$*P < 0.05$

Analysis of Variance for Maximum 6 Minute Recovery O_2 Debt

Source of Variation	df	SS	MS	F
Group	4	17.592	4.398	120.251*
Error	45	1.646	0.037	
Total	49	19.238		

$*P < 0.05$

Analysis of Variance for Percent Anaerobic

Source of Variation	df	SS	MS	F
Group	4	18120.452	4530.113	217.270*
Error	45	938.255	20.850	
Total	49	19058.708		

$*P < 0.05$

ii) Deficit-debt ratio 1:1.6

Analysis of Variance for Total Net O_2 Cost

Source of Variation	df	SS	MS	F
Group	4	136.109	34.027	258.185*
Error	45	5.931	0.132	
Total	49	142.040		

*P < 0.05

Analysis of Variance for METS

Source of Variation	df	SS	MS	F
Group	4	2177.752	544.438	258.185*
Error	45	94.892	2.109	
Total	49	2272.644		

*P < 0.05

Analysis of Variance for Task VO_2 (aerobic component)

Source of Variation	df	SS	MS	F
Group	4	62.389	15.597	402.956*
Error	45	1.742	0.039	
Total	49	64.131		

*P < 0.05

Analysis of Variance for Percent Aerobic

Source of Variation	df	SS	MS	F
Group	4	21784.154	5446.038	248.557*
Error	45	985.979	21.911	
Total	49	22770.133		

*P < 0.05

Analysis of Variance for Maximum 6 Minute Recovery O_2 Debt

Source of Variation	df	SS	MS	F
Group	4	27.487	6.872	120.251*
Error	45	2.572	0.057	
Total	49	30.059		

*P < 0.05

Analysis of Variance for Percent Anaerobic

Source of Variation	df	SS	MS	F
Group	4	21784.154	5446.038	248.551*
Error	45	985.979	21.911	
Total	49	22770.133		

*P < 0.05

iii) Deficit-debt ratio 1:1.2

Analysis of Variance for Total Net O_2 Cost

Source of Variation	df	SS	MS	F
Group	4	172.899	43.225	229.649*
Error	45	8.469	0.188	
Total	49	181.368		

*P < 0.05

Analysis of Variance for METS

Source of Variation	df	SS	MS	F
Group	4	2766.392	691.598	229.649*
Error	45	135.519	3.012	
Total	49	2901.911		

*P < 0.05

Analysis of Variance for Task VO_2 (aerobic component)

Source of Variation	df	SS	MS	F
Group	4	62.389	15.597	402.956*
Error	45	1.742	0.039	
Total	49	64.131		

*P < 0.05

Analysis of Variance for Percent Aerobic

Source of Variation	df	SS	MS	F
Group	4	26873.934	6718.484	300.420*
Error	45	1006.364	22.364	
Total	49	27880.298		

*P < 0.05

Analysis of Variance for Maximum 6 Minute Recovery O_2 Debt

Source of Variation	df	SS	MS	F
Group	4	48.866	12.217	120.251*
Error	45	4.572	0.106	
Total	49	53.438		

*P < 0.05

Analysis of Variance for Percent Anaerobic

Source of Variation	df	SS	MS	F
Group	4	26873.934	6718.484	300.420*
Error	45	1006.364	22.364	
Total	49	27880.298		

*P < 0.05

APPENDIX B

CALORIC COST

It is well documented that the caloric value of O_2 varies depending upon the particular fuel utilized (6,39,42), i.e., the caloric value per litre of O_2 is 5.0 kcal for carbohydrate and 4.7 kcal for fat. Since carbohydrate is the major energy source during work or exercise of short duration it was assumed that it was the fuel utilized during the work tasks and therefore the factor 5.0 kcal was employed in the determination of the caloric cost. The caloric value per litre of O_2 at rest is somewhat less, approximately 4.8 kcal because the fuel utilized is some combination of fat and carbohydrate. In this study resting O_2 consumption was not measured but rather pre-exercise was. Since the actual caloric value per litre of O_2 for pre-exercise was not known 5.0 kcal was employed in the caloric cost calculation. Actually the caloric value per litre of O_2 under this condition was probably closer to 4.8 than 5.0, however, this would only change the results further in the direction of significance. Since the major consideration was the comparison of the four work tasks the precise determination of the caloric cost of pre-exercise was not necessary.

VITA AUCTORIS

Birthplace: London, Ontario, Canada

Birthdate: March 15, 1951

Educational Background:

1969	South Secondary, London, Ontario	H.S.S.G.D.
1973	McMaster University, Hamilton, Ontario	B.A.
1973	McMaster University, Hamilton, Ontario	B.P.E.
1973-75	University of Windsor, Windsor, Ontario	GRADUATE RESEARCH

Professional Societies:
Canadian Association of Sport Sciences (CASS/ACSS)
American College of Sports Medicine (ACSM)