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MINING TASK ANALYSIS: MECHANICAL AND METABOLIC CONSIDERATIONS IN A DEEP CANADIAN MECHANIZED MINE

by

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THESIS

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ABSTRACT

Purpose: The objective of this thesis was to examine work in mines. Specifically, part #1 performed *in-situ* time/motion analyses of common mining jobs and part #2 analyzed *in-situ* energy expenditures while working in a mine. **Methodology:** *Part #1-* task and sub-task duration and subjective work intensity were investigated for thirty eight subjects from six different mining jobs. These jobs were then organized into 4 groups for statistical analysis based on precedence: Group 1 (Bolting & Screening (attaching steel mesh to walls and ceiling), Group 2 (Conventional Mining (using a hand-held drilling carriage to drills holes in rock walls and ceiling)), Group 3 (Support Services (mechanic, welder, pipe layer)), Group 4 (Production Drill (using a machine mounted drilling unit), Scooptram™ (ore transport with no air conditioner), Shotcrete (concrete applied by spraying)). *Part #2-* In-situ metabolic energy expenditures were estimated through indirect open circuit calorimetry and deep tissue and skin temperatures were measured for those same groups. **Results:** *Part #1-* twenty three common mining tasks were identified with differences identified between various group for time and intensity. *Part #2-* metabolic requirements between groups were similar with one difference identified between groups 3 and 4 ($P < 0.05$). Deep tissue and skin temperatures did not change significantly through the course of a work day. **Conclusion:** *Part #1-* a variety of tasks is performed by each group and there is no uniform work protocol. *Part #2-* each mining group's metabolic energy expenditure requirements to perform various mining tasks are similar.

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ABBREVIATIONS

SkBF	Skin blood flow
T_c	Core temperature
T_{es}	Esophageal temperature
T_{re}	Rectal temperature
Tpill	Deep tissue temperature
T_{set}	Temperature set point
T_{ty}	Tympanic temperature

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Body heat content is a function of the mass and specific heat capacity of various body tissues and their change in temperature. A change in body heat content is thus reflected as a change in body temperature. Ultimately, changes in regional body temperature are affected by 1) the rate of exchange between the surface of the body with the environment and 2) internal heat exchange between tissues and compartments of the body. This system of overall heat exchange under nonequilibrium conditions can be represented by the general heat balance equation:

$$S = M \pm (R \pm C) \pm W - E$$

Where: S is the net heat gained or lost
M is metabolic heat production
(R + C) is the radiation and conductive heat loss
W is the mechanical work performed
E is evaporative heat loss
± indicates that the flow of heat energy can be gained or lost by the body

During exercise or physical work (W), the metabolic rate increases above resting levels due to increased muscle activity and is represented as M. Heat production is the difference between M and W. As exercise continues the increase in convective heat transfer between muscle and blood results in heat redistribution (C) and can be seen as an eventual rise in temperature of all the tissues of the body. This convective capacity of blood to redistribute heat to the tissues was observed by Ducharme and Tikuisis (Ducharme and Tikuisis 1994) during cold water submersion of the hand and forearm during steady state exercise. They concluded that blood flow to the forearm tissues accounts for ~85% of total heat loss to the environment. Thermoregulatory mechanisms are activated as a function of changes in internal thermal equilibrium. Heat loss mechanisms are activated ((R + C) and E), in response to the increases in heat production, resulting in an increase in the rate of whole-body heat loss. When heat loss is equal to heat gain, thermal balance is established and thus S equals zero. If there is uncompensated heat gain, that is when S is greater than zero, core temperature (T_c) will increase. Thus, when S is positive, there is a net heat gain; conversely, when S is negative, there is a net heat loss. The relative contribution to heat loss (R + C) and E are dependent on the quality of the environment, the exposed skin surface area, and the magnitude of convective air flow over the exposed surface area of the skin. Net heat gain or net heat loss is determined to a large degree by the gradient of partial pressure of water (P_{H2O}) between the air and on the skin surface, and temperature between the air and the body surface temperature.

A geothermal gradient (R) and autocompression of air has been recorded as a function of increasing depth (Marx 1998). Since there appears to be a trend to mine deeper, miners are exposed to increasing thermal loads as a result of changes in ambient conditions. Many factors including the blasting of virgin rock, drilling, the geothermal gradient and autocompression of air may give rise to eventual compromise of thermolysis subsequent to changes in radiative, conductive and evaporative heat loss capacities. Ambient air pressure is influenced by air flow resistance and gravity. These two factors tend to decrease P_{H2O} gradient which decreases the efficiency of sweating. Factors such as higher ambient temperatures, the lower cooling capacity of the air, decreased exposed surface area of the skin (due to the personal protective equipment) and the metabolic demands (heat loads) of manual work (M) is not conducive to heat loss processes. The capacity to reduce heat loads through decreasing metabolic work is limited; however, though costly, manipulating the working environment to aid in heat loss is more effective (Marx 1998; Brake and Bates 2002). Several working safety standards/indices have been created as indicators of heat stress in mine workers Houghten and Yaglou (Houghton 1923) Bedford (Bedford 1945) Yaglou and Minard (Yaglou 1957) McArdle, et al (McArdle 1947) Belding and Hatch (Belding 1955) Moran and Mendal 2002. These indices were developed to estimate net heat gain or net heat loss in the body.

Heat stress indices can be classified into two main categories: 1) effective temperature scale (ET), which is based on ambient temperature and radiation; 2) rational heat scale, which focuses more on physiological parameters. Several ET and rational heat scales have been used in determining the most accurate heat stress indicator. Some of the measured parameters for the ET models include air temperature, humidity, and heat radiation. This type of index mainly focuses on R + C and E variables of the heat balance equation. The ET scale excludes W and M in the calculation of heat stress. Some of the rational heat scale variables include heart rate, required sweat rate (the minimal amount of sweating required by an individual to maintain an S equal to zero), T_c (rectal or tympanic), oral temperature, skin temperatures, and metabolic energy expenditure. This type of index estimates the M and E variables of the heat balance equation. Of these indices, the most generally accepted index in deep Canadian mechanized mines is the ET Wet Bulb Globe Temperature (WBGT). The WBGT accounts for R + C and E for the portions of the heat balance equation.

WBGT indoors:

$$WBGT = 0.7\ t_{nwb} + 0.3\ t_g$$

WBGT outdoors:

$$WBGT = 0.7\ t_{nwb} + 0.2\ t_a + 0.1\ t_g$$

t_{nwb}= natural wet bulb
t_a = air temperature
t_g= temperature of a 150 mm diameter black globe

Yaglou and Minard (Yaglou 1957) developed the WBGT with its first industrial application by military personnel in hot climates. Subsequently, the WBGT has been adopted by the American Conference of Governmental Industrial Hygienists (ACGIH) as an indicator of heat strain in the work place. The WBGT is a useful heat stress index in the industrial setting because of its simplicity and cost effectiveness. Although this index is suited to acclimated individuals, two types of clothing (permeable and impermeable), and rest/work intervals, it estimates at best, the metabolic component of the heat balance equation. Therefore to increase the accuracy of the WBGT a better estimate of the metabolic variable in the heat balance equation is needed. Time motion analysis is one method that can increase the accuracy of measuring metabolic activity.

Time motion analysis has been used particularly in the sporting environment (Reilly and Thomas 1976; Deutsch, Maw et al. 1998; Deutsch, Kearney et al. 2007) to quantify temporally and mechanically the performance of different types of tasks. Deutsch et. al. (Deutsch, Kearney et al. 2007) observed differences between various positions on a rugby team that perform similar tasks. They also noted that all players playing the same position do not perform the same amount of work during a game (M and W). If this technique is applied to the mining industry, it maybe presumable to estimate different metabolic load or energy requirements (M) for the different jobs. Differences in common mining tasks have been characterized by other investigators (Williams, Wyndham et al. 1968)Durnin, 1967), however, there is a paucity of knowledge for work in mechanized mines. By using time motion analysis in conjunction with direct metabolic energy expenditure measures, it is possible to identify potential heat load differences between different mining occupations under similar environmental conditions.

Therefore the goal for part 1 is to characterize the different tasks performed in a deep Canadian mechanized mine, while for part 2 the goal is to measure the metabolic rate required to perform these mining tasks.

1.1 Rationale

In literature a number of different tasks performed mining personnel are discussed. However, limited research has been performed on quantifying the tasks performed and the metabolic cost to work in a deep mechanized mine, more specifically, a deep Canadian mechanized mine. Therefore the purpose of part 1 is to identify tasks performed by common mining occupations. Part 2 will then analyze in-situ, the energy expenditure for those tasks as identified in part 1.

1.2 Hypothesis

Part 1

There is a difference between task requirements between occupations

Part 2

There is a difference between all tasks in the metabolic rate required for their performance

1.3 Objectives

The objectives of the study were to:

-Part 1; investigate common mining occupations and their associated tasks under non-stressful working conditions;

-Part 2; investigate the metabolic energy requirement to perform those tasks from part 1 and also to measure the deep tissue and skin temperature changes throughout the workday.

1.4 Relevance

This study will help to classify the type of work tasks performed and the energy requirements of work in a deep Canadian mechanized mine. Cataloguing tasks performed (Part 1) and their associated metabolic cost (Part 2) will give a better estimation of heat load on the worker during performance of these tasks.

1.5 Delimitations and Limitations

All data collected in these two parts are for specific occupations. Attempting to generalize for other mining occupations may not be appropriate, as their requirements may differ.

Sample sizes for each of the groups are not large enough for statistical significance.

This study will identify non-stressful ambient working conditions for one mine in Canada. The mechanization level of each mine and the types of mines vary across the country. Information collected is generally applicable to deep mines with similar levels of mechanization and rock type. Open face mines (surface mines) may not find this research as applicable as they may not encounter the same thermoregulatory problems as deep mechanized mines. Therefore, this research is limited to mines that have similar levels of mechanization and occupation requirements.

In this study, all subjects are males; therefore, it will exclude the effects of heat stress on the female mining population.

1.6 Definitions

Labor time – arrival time until departure time at a predetermined work site (as determined by the subject's supervisor) which excludes lunch/rest periods

Occupation – job description/classification (e.g.: Scooptram™ operator)

Task – specific requirements of an occupation (e.g.: driving, spraying water)

Work shift – the time from exiting until entering the elevator which excludes lunch/rest periods

CHAPTER II

REVIEW OF LITERATURE

2.0 Introduction

The aim of this investigation was to 1) classify the tasks performed for each mining occupation (observational) and 2) to measure the metabolic energy expenditure while performing the identified tasks in part 1. This review describes the current literature of mining tasks in terms of equivalent metabolic requirements and in the context of the heat balance equation. Furthermore, the heat stress indices used to protect workers, in relation to the heat balance equation, will be laid out. This will provide a framework necessary to understand the requirements and limitations to work in a deep Canada mechanized mine.

2.1. Heat balance equation under mining conditions

The quantity of heat generated by increased metabolic activity (M) during work varies according to task (Sawka, Miles et al. 1982) and its intensity. Only a fraction, 20 to 30 % (Whipp and Wasserman 1969), of the metabolic energy is transferred into mechanical work (W). For example, a 400 W metabolic load may yield 280 to 380 W of heat production. If this heat energy is not dissipated from the body, heat storage occurs with will a resultant increase in average body temperature. Therefore, the rate of net heat storage determined by the relative rate of metabolic activity and net heat exchange with the environment. This is indicated by S in the heat balance equation:

$$S = M \pm (R \pm C) \pm W - E$$

Where: S is the net heat gained (indicated by positive, negative, or zero)
M is the internal metabolic heat production
(R + C) is the net radiative and conductive heat exchange between the body surface and the environment
W is the mechanical work performed or done on the body
E is evaporative heat loss from the body surface including the pulmonary surface
*all units are expressed in Watts

Under high temperature ambient conditions, where the capacity to lose heat is low or negative, the evaporative rate (E) becomes a major means for thermolysis. The rate of E is modified by convective air flow over the exposed skin surfaces. Greater convective rates increase the rate of heat energy exchange between body surfaces and the environment by E and C. In this case, evaporation (E) provides the only means by which net heat loss can occur. Under conditions where the P_{H2O} gradient between the body and environment and/or when exposed body surface area is decreased; the overall rate of evaporative heat loss is reduced.

Mining apparel typically consists of: safety foot attire, long trousers, long sleeve shirt, and a safety helmet. With reduced exposed skin surface are, thermolytic capacity is reduced. In mining rescue personnel, thermolytic efficiency is further reduced by gloves, respirator/scrubber, and/or full fire retardant suits. As a result, these individuals have greatly reduced heat loss capacity. Under the aforementioned conditions, there is a tendency of net heat gain in the body which is manifested as a rise in deep tissue temperature.

2.1.1. Metabolism (M)

Indirect calorimetry is one method used to estimate the amount of metabolic activity in the body. This method of metabolic estimation is as accurate as direct calorimetry over long periods of time (Dauncey 1980). The benefit to direct calorimetry is that it measures the net heat exchange over large time periods, whereas metabolic energy expenditure is estimated by indirect calorimetry on a breath by breath basis.

The stoichiometric reduction of substrates and products of oxidation, permit the production quantity of heat generated in a given metabolic reaction. This estimation has been identified through the nonprotein respiratory quotient (NPRQ). Weirs' (Weir 1949) equations shows that when NPRQ equals 0.707, the nonprotein VO_2 ($NPVO_2$) is entirely due to lipid oxidation and its caloric equivalent is 19.61 kJ (4.686 kcal) for one litre of oxygen consumed, whereas the NPRQ equals 1.0 when $NPVO_2$ is entirely due to glucose oxidation and the caloric equivalent of one litre of oxygen consumed is 20.95 kJ (5.007 kcal) (Jéquier, Acheson et al. 1987). From these equivalents a formula is created to determine the metabolic energy expenditure of the body:

Conversion of gas volume into STPD

$$V_{STPD} = \frac{273}{(273+T_a)} * \frac{(P_b - P_{H_2O})}{760}$$

Where V_{STPD} = corrected volume of gas to standard temperature pressure dry

T_a = ambient temperature °C
P_b = atmospheric pressure in mmHg
P_{H20} = partial pressure of water vapor

Determination of ventilated gas ratios

$$RER = \frac{\dot{V}O_2}{\dot{V}CO_2}$$

Where RER = Respiratory Exchange Ratio
VCO_2 = volume of expired CO_2/min
VO_2 = volume of expired O_2/min
Determination of energy expended

$$KJ/\min = \left(\left[\frac{RER-0.7}{0.3} \bullet 21.116^*\right] + \left[\frac{1-RER}{0.3} \bullet 19.606\right]\right) \bullet VO_2 (l/\min) STPD$$

*Note: the $NPVO_2$ used here is 21.116 kJ (5.047 kcal) versus 20.95 kJ (5.007 kcal) of Jéquier (Jéquier, Acheson et al. 1987). This is due to the different O_2 constant used for carbohydrate utilization.

Metabolic energy expenditure measurements, in conjunction with changes in deep tissue temperature, can provide a better understanding of heat load. From these observations, the accuracy in measuring heat stress experienced by workers in the mines may be achieved.

2.1.2. Time Motion Analysis

The utilization of time motion analysis in sports is common practice. Cataloguing of tasks performed, intensity of these tasks, and time spent doing these particular tasks are important in the preparation of the athlete for competition. Through time motion analysis and physiological measurements from previous studies (Reilly and Thomas 1976; Deutsch, Maw et al. 1998), it has been shown that the physiological demands within the rugby team vary significantly. Since different positions have different requirements, being exposed to the same preparations may not adequately prepare the athletes for competition.

This same principle applies equally to the mining industry, where, ostensibly the task requirements for each occupation vary notably. Several common mining tasks have been analysed by Williams and Wyndham (Williams, Wyndham et al. 1968) within a coal mine. Although this list was not exhaustive, it does provide a framework for mining task analysis in a mechanized mine. At this point only limited research has been carried out on time/motion analysis of tasks performed in deep Canadian mechanized mines.

Noteworthy are the limitations to this particular type of analysis. There are potential discrepancies within the same occupation and the frequency of each task being performed within that occupation. Inconsistencies within occupations will at most provide an estimation of the task requirements for each occupation.

2.1.3 Transfer of Heat Energy

Heat exchange is classified as sensible (dry heat loss) or insensible (wet heat loss). Both classifications will be discussed in further detail below.

2.1.3.1 Dry Heat Loss

Conduction

Conductive (C) heat exchange results from the temperature difference between two surfaces, typically the skin and the environment. When the skin surface temperature is greater than the environment, the gradient is said to be in favour of heat loss by conduction and radiatioin. When skin temperature is less than the environment, heat gain is favoured. The rate at which heat is exchanged by conduction to the environment is dependent on the amount of exposed body surface to convective flow of fluid. Blood has been shown to conduct heat to other tissues (Ducharme and Tikuisis 1994); therefore, the rate of skin blood flow (SkBF) will influence the rate of conduction.

Conductive heat loss also occurs through ventilation and increases when the rate of ventilation increases. If the environmental temperature and P_{H2O} gradients are lower than those in expired ventilation, then both heat and moisture will be added to the environment. This energy transfer accounts for approximately 10% (10-15W) of total heat loss at rest under normal conditions (Hanson 1974). Larger amounts of heat loss could occur during exercise due to increase breathing frequency.

Radiation

The vibration of molecules will emanate radiation only under conditions where it its temperature is above absolute zero.

Convection

In its most general form, convection is the flow of a liquid over a surface. Factors which determine the rate of transfer of energy between surfaces by conduction are the flow rate between these surfaces and their specific heat transfer capacity.

2.1.3.2. Wet Heat Loss

Evaporation

Evaporation (E) is the loss of energy through the change of physical state from liquid to gas. For humans, E of water occurs at the skin (sweating) and pulmonary surfaces (respiration). When there is a change in the state of a liquid to a gas, evaporation occurs and the surface has the ability to cool.

The rate of heat exchange will vary according to the amount of clothing worn by the individual. In cold environments, where minimal amount of skin surface is exposed, the capacity to cool the body is reduced. Dependent on the type of clothing worn, either loose fitting garments or a biohazard suit, a microclimate is created that will greatly affect thermolysis. Therefore, the capacity for thermolysis is limited by clothing type.

2.2 Mining Environment

Mines throughout the world differ according to their geography, depth, ore, and mechanization level. As a result of these variables, each mine becomes a unique working environment. The environmental working conditions and the various energy expenditure requirements to perform tasks in mines are the focuses of this section.

2.2.1. Mining environment

As previously stated, the thermal gradient between the skin and ambient conditions influences the rate of net heat exchange. Under high temperature ambient working conditions, a decrease in the thermal gradient between the skin and environment tends to limit the capacity to cool the body. Limited heat loss capacity of the ambient environment in mines has been recorded by various authors throughout the world. Donoghue (Donoghue and Bates 2000) noted mean wet bulb temperature, dry bulb temperature, and WBGT values of 29°C, 37.4°C, and 31.5°C respectively in Australian mines. Kalkowsky and Kampmann (2006) measured mean wet bulb temperature, dry bulb temperature, and WBGT values of 28.2°C, 31.2°C, and 29.1°C in a German coal mine. Pal and Sinha (1994) identified copper mine dry temperatures ranging from 22°C to 32°C in India. In a UK coal mine, Weller (1981) measured a Basic Effective Temperature between 26.6°C and 27°C, whereas Chilton and Laird (Chilton and Laird 1982) measured 29.4°C.

Accompanying the high temperature ambient conditions is the thermal gradient in virgin rock temperature (VRT). A VRT gradient, from surface to deeper rock strata, of 10°C to 22°C/km (Marx 1998) has been observed in a South African mine. Canada's Creighton mine has recorded a VRT of 48°C at 2400 m (Thibodeau 1999), in contrast, Germany has observed a 30 m/K thermal gradient (Piekarski 1995). These findings support the notion of increasing thermal heat loads with increasing depth. This suggests that workers will experience higher heat loads during work, independent of intensity.

2.2.2. Mining Tasks

Depending on the level of mechanization in a mine, energy expenditure requirements will vary according to tasks performed. This is particularly important when ambient conditions become stressful. As R and C become high, E becomes low (as a result of elevated wet bulb temperatures) and there is less capacity to cool. Thus in order for S to remain at zero, minimal heat can be contributed by metabolic processes.

Various authors have measured metabolic heat loads in mines throughout the world. Shoveling, as measured by Bethea (Bethea 1980) and Leithead and Lind (Leithead 1964), ranged between 266 Wm^{-2} and 407 Wm^{-2}. Variations in the energy expenditure for drilling have also been observed; Leithead and Lind (Leithead 1964) noted this activity to be 217 Wm^{-2}, whereas Graves (Graves, Leamon et al. 1981) gives a range between 240 Wm^{-2} and 290 Wm^{-2}. Williams and Wyndham (Williams, Wyndham et al. 1968) measured the oxygen consumption for tramming an empty cart versus tramming with a 2000 lb load. They found values ranging from 0.45 l/min to 1.4 l/min. Typical coal mining work rate levels were found to be between 290 W and 315 W in mechanized or partially mechanized mines (Sieber 1963). Weller (Weller 1981) used data from South African gold mines to estimate the metabolic work loads in UK potash mine workers; he estimated a range between 274 Wand 470 W.

To protect workers from environmental and metabolic heat stressors, various indices have been developed. These indices are all indirectly based on the heat balance equation (examples can be seen below). The level of mechanization in a mine is of particular importance in heat balance. It is assumed that greater levels of mechanization will decrease the need for physical labor. As a result, there will be a decrease in the metabolic contribution to the body. However, physical work has been observed by Brake and Bates (Brake and Bates 2002) to become self paced accompanying high ambient conditions. Therefore this should be represented as a decrease in M in the heat production regardless of mechanization level. Hence, with decreases in metabolic activity, miners are able to work for extended periods of time without experiencing heat stress. Many authors have investigated the metabolic requirements to perform various tasks in different types of mines. A common finding within the literature is that there are variations in the type of tasks being performed and the subsequent energy requirements of these tasks. Therefore, the accuracy of those heat stress indices, which encompass metabolic energy expenditure in their calculations, is questionable.

2.3 Monitoring Miner Safety

In the mining industry, working ambient conditions may not necessarily favor heat loss. In other words, ambient working conditions may favor net heat gain, which can eventually be seen as a rise in T_c. In order to minimize the change in worker T_c, there is a need to control the metabolic rate and/or monitor the ambient working environment. When the WBGT is high, the environment heat exposure times can be decreased, ultimately protecting the worker from heat stress related illnesses. Several working safety standards/indices have been created to allow for safe repeated bouts to heat exposure.

These indices can be classified into two types: 1) effective temperature scale (ET), which is based on meteorological readings of temperature and radiation; 2) rational heat scale, which is based more on physiological parameters. Several ET and rational heat scales have been used when creating an accurate heat stress indicator. Examples of heat stress indices are given below, however the generally accepted index from this list is the effective temperature reading WBGT.

2.3.1 Empirical Indices

Effective Temperature (ET)

This index was first developed by Houghten and Yaglou (Houghton 1923) as a comfort scale. This scale combines the effects of temperature, humidity, and air convection on the human body.

Corrected Effected Temperature (CET)

The CET, as proposed by Bedford (Bedford 1945), is similar to ET; however, globe temperature is used rather then air temperature to incorporate radiant heat energy.

Values associated for both the ET and CET as recommended by the WHO for unacceptable work levels are: 30°C for sedentary activities, 28°C for moderate work levels, and 26.5°C for hard work. For individuals who are fully heat-acclimated, values of 2°C are added to each work level.

Wet Bulb Globe Temperature (WBGT)

WBGT was developed by Yaglou and Minard (Yaglou 1957) for use in the United States military and is corrected for one type of clothing.

WBGT indoors:

$$WBGT = 0.7\ t_{nwb} + 0.3\ t_g$$

WBGT outdoors:

$$WBGT = 0.7\ T_{nwb} + 0.2\ t_{ta} + 0.1\ t_g$$

t_{nwb}=temperature of a naturally ventilated wet bulb thermometer
t_a =air temperature
t_g=temperature of a 150 mm diameter black globe thermometer

The American Conference of Governmental Industrial Hygienists (ACGIH) has adopted this equation for the estimation of heat strain in the work place. From these WBGT values, a work to rest ratio has been developed to reduce heat stress.

Table 1. Work Rest Ratio for WBGT for Acclimated and Unacclimated Individuals as Modified From Varley (Varley 2004)

Work Demands	Acclimatized				Unacclimatized			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
100% work	29.5	27.5	26.0		27.5	25.0	22.5	
75% work, 25% rest	30.5	28.5	27.5		29.0	26.5	24.5	
50% work, 50% rest	21.5	29.5	28.5	27.5	30.0	28.0	26.5	25.0
25% work, 75% rest	32.5	31.0	30.0	29.5	31.0	29.0	28.0	26.5

2.3.2 Rational Indices

Predicted Four-hour Sweat Rate Index (P_4SR)

Predicted four-hour sweat rate index was developed by McArdle, et al (McArdle 1947). This index predicts the required total sweat loss (litres) during a four hour bout of exposure. This indices provides information to the worker with regards to how much evaporation is required during the working period such that, no net heat will be gained.

The P_4SR is then:

$$P_4SR = B_4SR + 0.37 I_{clo} + (0.012 + 0.001_{Iclo})\ (M - 63)$$

If the men are clothed, increase the wet bulb temperature by 1.5 I_{clo} (°C).
The B_4SR is the basic four hour sweat rate

Heat Stress Index (HSI)

Heat stress index developed by Belding and Hatch (Belding 1955) is based on the physical analysis of heat exchange. This value is based on the ratio of evaporative heat loss required for heat balance (E_{req}) and the maximum evaporative capacity (E_{max}).

$$W = E_{req}/ E_{max}$$

Where E_{max} is derived by:

$$E_{max} = 18.3\ v^{0.6} * fpcl\ (P_{sk} - P_a)\ W*m^{-2}$$

18.3 is the coefficient for evaporative heat transfer
fpcl is the clothing permeation coefficient
P_{sk} is the saturated skin vapour pressure at T_{sk}
P_a is the saturated ambient vapour pressure

Physiological Strain Index (PSI)

The physiological strain index (Moran and Mendal 2002) is based on T_{re} and heart rate (HR).

$$PSI = 5(T_{ret} - T_{re0}) \cdot (39.5 - T_{re0})^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1}$$

T_{ret} and HR_t are simultaneous measurements of rectal and heart rate
T_{re0} and HR_0 are the initial rectal and heart rate measurements

Though the index can differentiate between hot-dry and hot-humid environments, these conditions have not been validated for women. Berggren and Christensen (Berggren and Christensen 1950) showed that heart rate can be used advantageously for work of short duration, whereas body temperature determinations can be used for long work durations. They cautioned that heart rate and body temperature can vary independently of metabolic rate. Moran et al., (Maron, Horvath et al. 1976) indicates that the applicability of this equation applies only to continuous work, which is not indicative of typical mining practices.

2.3.3 Limitations to the Indices

Within the ET and CET indices, only environmental conditions are considered. The WBGT also measures environmental parameters; however, one particular type of clothing was taken into consideration when the index was created. Incorporating clothing into the index increased the accuracy of the heat strain index. One limitation common to all the three indices is the absence of a metabolic component to the prediction of thermal strain.

The rational heat stress scales account for predicted metabolic heat production in the body. The predicted four-hour sweat rate estimates the cooling capacity required from sweating for a four hour period. Unfortunately, this index does not consider metabolic strain, clothing, and non-acclimated men. Also, it is difficult to accurately determine if workers are sweating adequately under ambient conditions. Another limitation to this index is that workers may not be acclimated when working in hot environments due variables such as scheduled time off, shift work, or vacations.

One limitation of the HSI is the clothing type, such as a biohazard suit being worn during work. Under such circumstances, the equation then becomes $E_{req} = E_{max}$. A foreseeable drawback from the PSI index is that it is predictive in nature. Since the index measures the physical states of the individual after work has been done in a stressful environment; therefore, this index can not predict heat stress. Only when a worker keeps a log of ambient conditions and physiological temperatures, can this index protect the worker.

Though all indices described above predict heat stress, it is the WBGT which is the simplest to use, in lieu of its cost and time effectiveness. With corrective factors such as worker attire and metabolic work (job type is known by the worker), the accuracy of the WBGT can be increased.

One common limitation to all indices is they are predictive in nature. These indices are statistical and those individuals who are the statistical out layers are either over or under protected by the heat stress indices. However, it is the under estimation of the heat stress indices that could place a worker in a precarious situation. Therefore, if individual monitoring systems were developed, this could ensure safety for miners who are under protected by the indices.

2.4. Physiology of Heat as a Response

2.4.1 Thermal Receptors

Neural sensors are located throughout the body from deep to superficial levels. Thermosensors respond to temperature changes and send signals to the CNS at the level of the hypothalamus. It is believed that cold sensors increase firing frequency to the brain when temperature is decreased. In turn, this process stimulates thermogenic responses. It was noted by Keating (Keatinge, Mason et al. 1986) that "cold receptors show transient increase in firing while their temperature is being lowered and a transient decrease while it is being raised, as well as sustained changes in discharged; warm receptors who converse effects but will have been virtually inactive at 29°C experiments…".

Thermosensors have the following generally accepted features:

- Some respond positively (higher firing rate) to temperature increases (warm-sensors) and some respond positively to temperature deceases (cold-sensors)

- Warm-sensors respond to a stepwise increase in temperature with brief bursts of intense activity (cold-sensors respond in a similar fashion to stepwise decreases in temperature
- There is generally a linear relationship between impulse and temperature
- Impulses may occur in bursts

To identify how cold and warm-sensors respond to elicit the sweating response, Waites (Waites 1962) found panting occurred when warming male sheep scrotal warm-sensors. Even though T_{re} dropped 0.5 - 1.0°C, local input from the scrotal temperature sensors over-rode the central thermal receptors by initiating the panting response.

2.4.2 Sweating as a Response

2.4.2.1 Skin temperature

Three factors control sweat rate: 1) core temperature, 2) mean skin temperature, and 3) local skin temperature (Heising and Werner 1987). Ivanov (Ivanov 1999) studied 197 neurons of the posterior hypothalamus and discovered that neurons responded to either skin, superficial, or deep thermostimulation. This suggests that skin sensors respond to the thermal gradient within the tissue. Ivanov went on to place two sensors in the skin at varying depths, with the third sensor placed externally. He was able to measure an increasing gradient with the various environmental temperatures, which also showed the beginning of cutaneous vasodilation. He also found that the firing rate to the hypothalamus varied depending on the depth of the skin stimulation sensor. Deep sensors were identified to have the greatest firing intensity from the fewest number of sensors, whereas a greater number of sensors were required to elicit the same firing rate from superficial sensors.

2.4.2.2 Mean Skin temperature

The thermoregulatory sweat test is designed to evoke the maximal sweat rate from an individual (Hsieh, McNeeley et al. 2001). During the test, participants are subjected to high ambient thermal strain followed by exercise in the same ambient conditions. It was found that maximal sweating was achieved by simple thermal strain. The addition of exercise, before or after the ambient stress, did not contribute to a further increase in sweat rate. This indicates that the metabolic component does not contribute to the sweating response under this particular test.

2.4.2.3 Local Skin Temperature

Typically, humans are fully or partially clothed. With heat transfer being optimal with direct skin contact to the environment, these exposed areas tend to favour heat loss. Sweat rates vary according to the number of glands per cm^2 and also depends on the region of the body that is under thermal strain. For 300 sweat glands/cm^2, the theoretical sweating limit has been estimated to be approximately 6000 nl/mn-cm^2 (Hsieh, McNeeley et al. 2001); however, the volume of sweat will vary depending on the magnitude of thermal strain.

For individuals who wear personal protective equipment that limits skin exposure, localized evaporation becomes an issue. If the exposed skin is such that rates of sweating are low, heat loss through evaporation is limited. Breathable clothing tends to allow evaporation to occur in those concealed areas.

2.4.2.4 Muscle Blood Flow

Blood flow to muscles is influenced by two main factors, sympathetic vasoconstriction and muscular metabolic activity. Under resting conditions, blood flow is kept at a constant rate; however, during exercise, the active muscles become vasodilated because of several factors: adenosine, low P_{O2}, high P_{CO2}, low pH, and lactic acid. Adenosine phosphate (from the break down of ATP) has the largest role in muscle vasodilation. Nitric oxide is released into the circulatory system from active muscles and vasodilates the smooth muscle surrounding the arteries. Vasodilation of the arteries/arterioles in the muscle beds (there are no pre-capillary sphincters in skeletal muscles, unlike the sites of oxygen exchange between cells and true capillaries) increases the volume of blood supply to the active muscles.

With the increasing muscle contraction and the rate of ATP breakdown, this increases heat production. Primary working muscles tend to be warmer then secondary muscles and hence heat is transferred along the thermal gradient; warmer muscle to cooler muscle. It is the conductive contact between muscle tissues and the convective ability of the flow of blood that aids in heat transfer. Eventually the capacitance for heat to be transferred and absorbed by cooler tissues becomes reduced and the excess heat must be exhausted through other avenues; the skin.

2.4.2.5 Skin Blood Flow

The hypothalamus, more specifically the preoptic/anterior hypothalamus (PO/AH) is responsible for thermoregulation (Benzinger 1959; Bligh 1998). Signals received by thermal sensors located throughout the body are integrated by the PO/AH and appropriate efferent signals are sent throughout the body. During exercise or warm ambient conditions, which elevate body temperature, thermolytic responses are initiated. Thermolysis is the loss of heat from the body. This typically occurs through evaporation and increased skin blood flow (SkBF).

Increased SkBF occurs through efferent stimulation of the sympathetic adrenergic vasodilating and vasoconstricting nerves on nonglobrous skin (skin typically with hair i.e. scalp), whereas stimulation of only sympathetic adrenergic vasoconstricting nerves are found on globrous skin (skin that is usually hairless i.e. palm of hands) (Charkoudian 2003). This efferent stimulation is the result of afferent input received from the thermal sensors located throughout the various depths of the skin. Differences in the rates of conductive heat exchange between nonglobrous and globrous skin can be attributed to arteriovenous anastomoses (AVA). Arteriovenous anastomoses are vessels that directly connect an arteriole and venule, which bypass the capillary bed. There is a tendency to have more AVA and innervations by sympathetic vasoconstrictor nerves in globrous skin in comparison to nonglobrous skin. However, AVA are innervated by both vasodilating and vasoconstricting nerves (Charkoudian 2003).

Two general receptor types have been found to effect SkBF; they are α and β adrenergic receptors. Typically, α adrenergic receptors are found on AVA while β adrenergic receptors are found in capillaries. Further, both receptors respond differently to cholinergic and bradykinin stimulus. Spence et al. (1972) noted that norepinephrine decreased AVA flow; phentolamine increased AVA and capillary blood flow however α receptors had a greater response than β receptors; isoproterenol increased capillary blood flow; and propanolol increased capillary blood flow while showing no change in AVA.

As blood flows through the terminal arteriole, precapillary sphincters surround the root of each true capillary at the metarteriole which in turn controls blood perfusion. Other influences, such as changes in pH, O_2 demand, and temperature alter blood perfusion into the capillary bed and eventually the postcapillary venule.

2.4.2.6 Hydration

Gisolfi and Copping (Gisolfi and Copping 1974) found that a rise in T_{re} was strongly correlated to a prediction of a rise in ~0.4°C T_{re} after each 1% loss, in lieu of post 2% bodyweight loss. This finding was confirmed by Moron et al., (Moran and Mendal 2002) who noted a 0.4°C difference between runners who lost 2.6% to 3.6% of their body weight. Greenleaf and Castle (Greenleaf and Castle 1971) showed that hypohydration caused a larger rise in mean body temperature ($\bar{T}_b$) when comparing hypo- to hyperhydrated and hypo- to ad libitum individuals' sweat rates and $\bar{T}_b$.

Maintaining T_{re} throughout exercise can be done by replacing 50-80% of sweat losses, which will also maintain plasma volume. When compared to replacing ~50% of sweat loss to replacing a larger percentage, a significantly higher T_{re} after 2 hours of exercise is apparent with lower fluid replacement (Cheuvront and Haymes 2001).

2.4.2.7 Acclimation

Several authors (Shvartz, Magazanik et al. 1974; Henane and Bittel 1975; Buono, Heaney et al. 1998) noted that after acclimation has occurred the threshold for sweating decreases such that a lower rectal temperature (T_{re}) elicits the sweating response. The efficiency of sweating increases during the acclimation process. Shvartz et al (Shvartz, Magazanik et al. 1974) found a 23% decrease in sweat rate and a 19% increase in E compared to unacclimated values. The reduced T_{re} during acclimation, which facilitates the lower threshold for sweating, is due to lower oxygen consumption. The increase in efficiency can be attributed to decreases in dripping sweat from the acclimation process.

2.4.2.8 Baroreflexes

Non thermal factors such as blood pressure control play a role in thermolytic responses particularly during and after exercise. It is observed that blood is diverted to the periphery, where conductive heat loss increases. During this shift, mean arterial pressure (MAP) decreases as a function of increased SkBF. During exercise, with the increase in blood flow to cutaneous pathways, cardiac output increases with the accompanying fall in measured renal and splanichnic blood flow. This process in turn restores MAP.

2.5 Thermoregulation Models

Heat balance within mammals, including humans, is a function of relative rates of heat gain and heat loss. Constant body temperature in humans is indicative of homeostatic control, where effecter responses are proportional to a set point differential, particularly with respect to heat balance. Control of heat balance is largely dependent on heat exchange between the body and the environment. The anterior hypothalamus is responsible for regulating heat storage in the body. With changes in heat stores, or total body heat content (H_b), a change in body temperature can be seen. Three theories have arisen to explain thermoregulation; set point, null zone, and heat content.

2.5.1 Set point

The most widely accepted model for thermoregulation is the temperature set point (T_{set}) theory (Cabanac and Massonnet 1974; Gisolfi and Wenger 1984; Cooper 2002; Bligh 2006). This theory is based on the principle that a sensor receives a stimulus and sends a signal to an integrator, where the signal is then processed and analyzed. If there is a load error (deviation of body T_{set}) then corrective thermoregulatory measures are sent to the effectors. As long as a load error is sensed, this negative feedback cycle will continue. If the load error is less then the T_{set}, thermogenesis will increase (i.e. increase in metabolic activity through shivering and decrease thermolysis), conversely if the load error is greater then the T_{set} then thermolysis will increase (i.e. increase in sweating and decrease thermogenesis).

2.5.2 Null zone

This theory suggests that there is no T_{set}, rather a thermoneutral zone. This zone could be considered the zone thermoneutrality; such that the thermoregulatory processes are minimally activated. Mekjavić et el (Mekjavic, Sundberg et al. 1991) brought forth evidence to support this zone theory. Mekjavić et el (Mekjavic, Sundberg et al. 1991) identified the zone between sweat initiation and shivering. This zone is approximated to be between 0.58 and 0.57°C in magnitude for esophageal temperature (T_{es}) and rectal temperature (T_{re}), respectively.

2.5.3 Heat content

Body heat content is a function of body mass, mean body temperature, and the specific heat capacity of the body. This theory suggests that the body regulates the exchange of heat between the body surfaces and the environment. Webb (Webb 1995) states that physiological responses, when detected, defend against changes in heat fluctuations between the body and the environment. For example, at the onset of exercise, Webb (Webb 1995) found that a quick increase in metabolic rate corresponded to an increased rate of heat loss before there was a change in T_c or minor changes in skin temperature. In other words, when there was an imbalance between the rate of metabolic heat production and rate of whole-body heat loss, there was a resultant change in body heat content, which eventually led to a change in T_c.

CHAPTER III

ARTICLE 1

Time Motion Analysis of Work Performed In Canada's Deep Mechanized Metal Mines

by

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Abstract

The purpose of this investigation is to characterize mining tasks using time motion analysis and to subjectively evaluate the metabolic energy expenditure to perform those tasks in a Canadian deep mechanized mine. Six mining occupations were grouped into four groups with a total of 38 volunteers. Time motion analysis, in conjunction with a subjective energy expenditure rating scale, was implemented to estimate the requirements to perform common mining tasks. Our investigation found varying intensities for the 23 common mining tasks identified and for the designated mining groups. Further investigation is required to increase the accuracy of the metabolic requirements to work in a deep Canadian mechanized mine.

Key words: task analysis – mining – mechanized mining – Canadian – energy expenditure

Introduction

Antidotal evidence has suggested that Canadian mining personnel are currently experiencing stressful environmental working conditions. Economic incentives to mine deeper are more prevalent. As a result, an associated increase in the geothermal gradient and ventilatory autocompression accompany these practices, which expose miners to greater potential heat loads. Strenuous occupational task requirements, in addition to environmental variables, translate to increasing likelihood of heat stress related illnesses.

Several authors have measured ambient mining conditions. For instance, Donoghue (5) noted mean psychrometric wet bulb, dry bulb, and WBGT values of 29°C, 37.4°C, and 31.5°C accordingly in Australian mines. Kalkowsky and Kampmann (12) measured mean psychrometric wet bulb, dry bulb, and WBGT values in a German coal mine of 28.2°C, 31.2°C, and 29.1°C. Pal and Sinha (16) identified in an Indian copper mine temperatures ranging from 22°C to 32°C. In a UK coal mine, Weller (20) measured a BET between 26.6°C and 27°C where Chilton and Laird (4) measured 29.4°C, and at Inco's Creighton mine in Canada, virgin rock temperature (VRT) of 48°C at 2400 m (19) have been measured.

Energy expenditures for mining tasks have also been measured by several authors. Shoveling, as measured by Bethea (2) and Leithead and Lind (14), ranged between 266 Wm^{-2} and 407 Wm^{-2}. Variations in the energy expenditure for drilling have also been observed; Leithead and Lind (14) noted this activity to be 217 Wm^{-2}, whereas Graves (10) gives a range between 240 Wm^{-2} and 290 Wm^{-2}.

Current literature identifies deep Canadian mines as having similar environmental conditions compared to mines in Australia, Germany, UK, and India. However, it is unknown how these Canadian mines compare with respect to task and work load intensities. By measuring ambient stress and characterizing work loads, heat loads experienced by mining personnel can then be estimated. The purpose of this paper is to characterize mining tasks, using time motion analysis, and to subjectively evaluate, according to the American Industrial Hygiene Association (AIHA) energy expenditure guidelines, the metabolic energy expenditures in a deep Canadian mechanized mine.

The findings from the first phase of a multiphase project will be disseminated.

Subjects and methods

Thirty nine mining personnel participated in the study while carrying out three essential mining occupations and one supplemental occupation (figure 1). Four groups were then created from these occupations: Group 1 (Bolting & Screening (attaching steel mesh to walls and ceiling) n=10), Group 2 (Conventional Mining (using a hand-held drilling carriage to drills holes in rock walls and ceiling) n=9), Group 3 (Support Services (mechanic, welder, pipe layer) n=9), Group 4 (Production Drill (using a machine mounted drilling unit) n=4, Scooptram™ (ore transport with no air conditioner) n=4, and Shotcrete (concrete applied by spraying) n=3). All measurements were performed between the months of February and May 2005.

Subject Description

Anthropometric measurements are given in Table 1 and include: height, nude weight, and full work attire (subject's weight in addition to all equipment and water/lunch carried to the work site) weight. Skin fold measurements were taken in accordance with the American College of Sports Medicine (9) guidelines to determine body composition

(3, 17). From these measurements, mean body density (7, 8, 11, 13, 18, 20, 23, 24) and body surface area (6) were calculated. All data was recorded and stored on a laptop (Panasonic Toughbook, CF-29, China).

Working Environment

Ambient conditions at each work site (ACR data logger Smart Reader 4, New Hampshire) (ACR) included: dry bulb (T_{db}), relative humidity, and ambient pressure. Video (Sony Handycam, DCR-DVD301, China) and environmental recordings began once the subject began work. During lunch and rest breaks, measurements and video analysis concluded. In general, the measurements and video recordings included: task and sub-task duration and subjective interpretation of work intensity (1).

The video camera was positioned on a stationary tripod located 3 to10 m from the subject. A brief description of the task performed and subjective work intensity (scale of 1 (low intensity), to 5 (very intense) to coincide with the AIHA (1) energy expenditure rage scale) was encoded for each minute of the work shift. Subsequent to the initial in-situ monitoring and assessment, the video recordings were re-analysed to confirm the original real time analysis.

Three synchronized ACR units were used to record the ambient conditions continuously during the work shift. The first unit was located at one end of the subjects work site 1 to 2 m above the ground, the second unit was placed at abdominal level of the subject (~ 1 m above work platform), and the third unit was placed underneath the air duct supply 1 to 2 m above the ground. See Figure 1 for work site map.

Statistical Analysis

Determination of the percent time allocated to a specific task was determined by averaging each worker's percentage of time task during their work shift. As the intensity of each task varied, the average intensity level performed by each occupation throughout the work day was calculated using the same method as in the determination of task duration. Time motion data was analyzed using a One-Way ANOVA by employing the dependent variables of percentage of time spent at a task (1 to 23) with the independent variable of job type group (1, 2, 3, and 4).

Results

Ambient conditions observed for each group are indicated in table 2. Group 4 was observed to have the highest average dry bulb temperature (T_{db}) of 26.8 ± 2.3°C, whereas Group 3 was observed to have the lowest T_{db} of 22.5 ± 3.8°C. Relative humidity was similar between all groups, with the smallest variation experienced by Group 4; 67.0 ± 3.5 %. Working ambient temperatures were measured concomitant to depth; a geothermal gradient of approximately 9°C/km was observed with a coefficient of determination value of 0.71 (figure 2).

Through the use of time motion analysis, several infrequent menial tasks were measured in each occupation. Since these menial tasks were not repeated in high frequency, they were grouped into a composite of one large task. An example of a composite task was 'miscellaneous', which comprised of activities such as shoveling or holding objects. In all, 23 common tasks were identified. A list and a brief description of each mining task are included in Appendix A.

Table 4 lists the 23 identified tasks and their associated metabolic energy expenditures. The table further depicts these energy requirements, according to each mining group, including an overall mining average. It was observed that the majority of the tasks performed ranged between several levels of energy expenditure. It was also noted that some groups did not perform certain tasks. Figure 3 shows the percent time spent by each group at each of the identified tasks with table 3 identifying statistical differences.

When amalgamating the data on percentage of time spent at a particular energy expenditure level, independent of task, Group 1 (bolting and screening) was identified as spending the largest proportion of time at the higher intensity levels (figure 4). Differences were observed ($p<0.05$) at intensity level 5 between Group 2 and Groups 1, 3, and 4. Not only does this figure show the variability between each group but also the variability within each group, as denoted by the large standard deviations at each intensity level.

Discussion

Our results show ambient working conditions in a deep Canadian mechanized mine as being less stressful then other mines identified by other authors. We identified some similar mining tasks as reported by other authors; however, our results differ with respects to energy expenditure. Although energy expenditure lists have been created, they are not specific to the tasks identified in this Canadian mine. Moreover, energy expenditure lists tend to be generic, making it difficult for comparisons. For example, arm and leg work (off road operation of trucks) (1).

Ambient working conditions measured were not as stressful as those identified in literature. This study being conducted between the winter and spring months in the

Northern Hemisphere may provide an explanation for this finding. Ambient T_{db} averaged 22.5 ± 3.8°C for group 3 and 26.8 ± 2.3°C for group 4. Relative humidity was found to fluctuate between 60.4 ± 16.4% to 67.3 ± 16.8% for groups 2 and 3, respectively. When plotting ambient temperatures as a function of depth (figure 2), a geothermal gradient of 9°C/km was observed. This is less than the gradient reported by Marx (15). If current air conditioning and mining practices continue, at approximately 3000 m, ambient conditions may reach 36°C.

Time motion analysis identified 23 tasks performed by miners. The task of shoveling, as measured by Bethea (2) and Leithead and Lind (14), ranged between 266 Wm^{-2} and 407 Wm^{-2}. Our estimates for shoveling, categorized under the miscellaneous task, ranged between level 3 and 4 (table 4). This energy expenditure intensity level corresponds to a range of 201 and 400 kcal/hr, or 116.8 and 232.5 Wm^{-2} (based on a mean BSA of 2.0 m^2). These values are lower than those of Bethea, Leithead, and Lind's. This suggests that the task requirements are different in the Canadian mine in comparison to mines observed by the previously mentioned authors. One explanation of this phenomenon could be the loads placed on the shovel are less than those measured in literature. Wiliams and Whydham (22) measured different oxygen consumption levels for different sized men, while shoveling at different rates and loads. Their findings support our explanation of shoveling and potentially the effects of a lower metabolic rate in other measured tasks. Independent of the group, a range of energy expenditures were observed for the majority of tasks performed. In addition to this, workers within the same group with regards to energy expenditure for a same task also varied.

The total percent of time spent by each group during a work shift at each of the 23 tasks can be seen in figure 3. Given the 23 identified tasks, the uneven distribution of time spent at each task emphasizes the unique requirements of each occupation. For example, the percent time spent on cutting, ranged between 0.0 ± 0.0 % for group 2 to 17.0 ± 1.0 % for group 4. Walking was one, among several, tasks that was common between all groups; however, the amount of time dedicated to this task varied between 1.3 ± 0.3 % for group 1 to 12.8 ± 6.4 % for group 3. Significant differences were identified between certain groups within the 23 tasks. These differences are identified in table 3.

The sum of all activities through the workday was tallied within each group, which revealed a disproportionate amount of time allocated to certain work intensities (figure 4). In figure 4, the percent time Group 1 spent at level 5 intensity was approximately 30%, whereas all other groups spent 5% or less. Therefore, it can be induced that Group 1 has the most physically demanding occupation. Groups 3 and 4 appear to be similar in their work intensities throughout the scale. In addition, Group 2 spent approximately 60% of the work shift at intensity level 3.

It is important to note that there are large variations observed with regards to intensity levels within each group. This disparity is the result of the variation in the intensity levels between each miner in each mining task. Therefore, more precision is needed before generalizations can be made. However, if a quick estimation of task or group energy expenditure is required before our observations can be implemented.

Conclusion

From this investigation, it can be concluded that the ambient mining conditions experienced in a deep mechanized Canadian mine differ from those experienced by other regions of the world, however the geothermal gradient is comparable. Twenty three common mining tasks were identified. The amount of time spent performing those tasks during a work shift varied between each group. This variation identifies the unique work requirements for each group.

Group metabolic energy expenditures were observed to be at levels 3 and 4. Group 1 spent the most time at level 5 which identifies this group as having the most intense occupation. Variability in observed intensity levels between groups could be the result of objective grouping or classification of the tasks. For example, the task of miscellaneous was a composite of several infrequent tasks. When several tasks were performed in a one minute interval, it was the most frequently performed task which was designated as the main task for that given minute. This technique could potentially exclude intense tasks performed for short bouts, such as lifting a heavy object.

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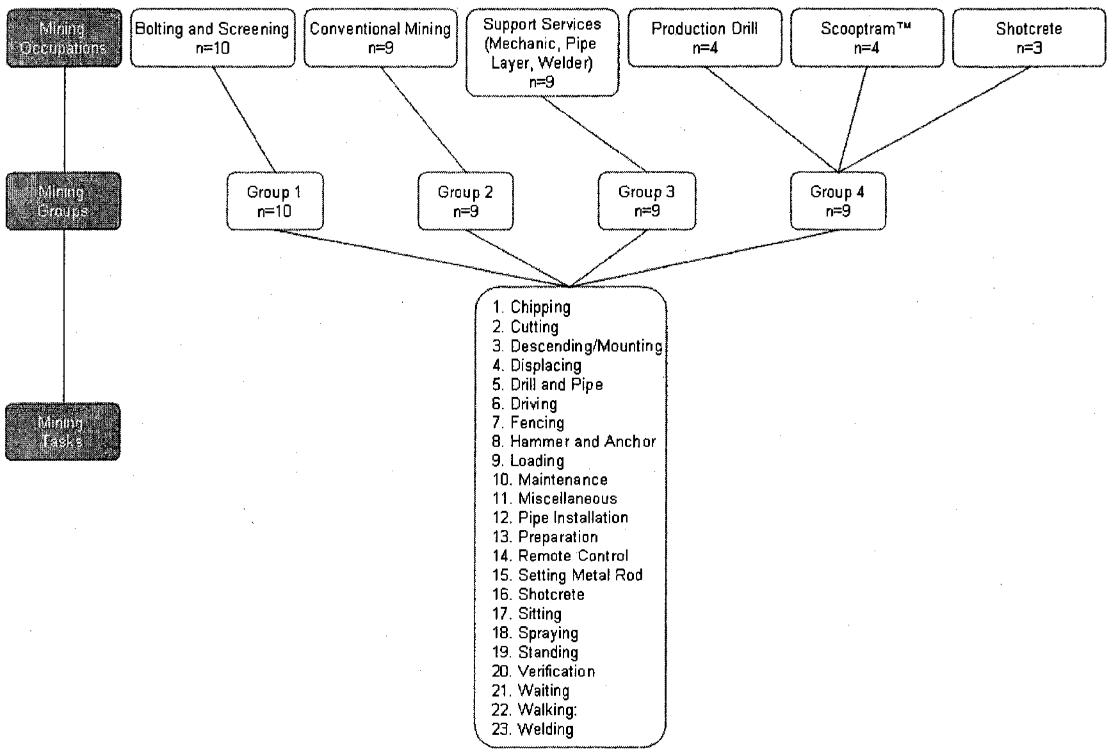

Figure 1. Schematic representation of mining groups and the identified tasks performed during a work shift.

Figure 1. Sketch of a work site and location of instruments used by the investigators in relation to the worker

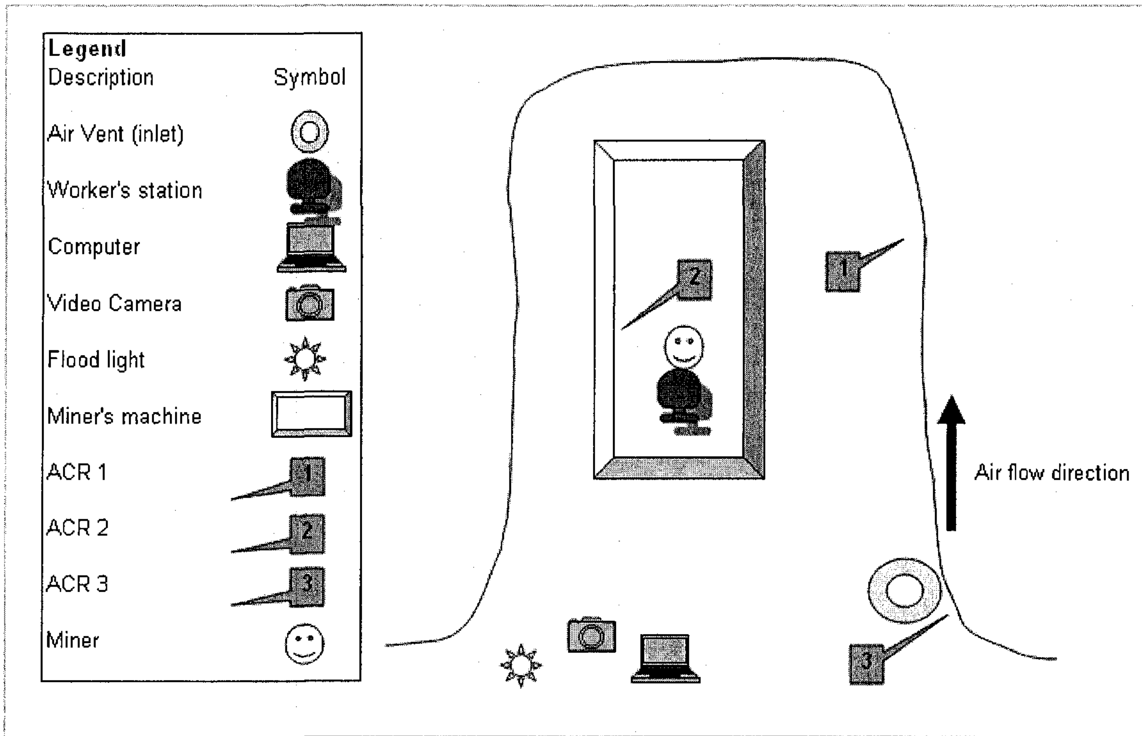

Table 1. Anthropometric data for each mining group

	Group 1 n=10	Group 2 n=9	Group 3 n=10	Group 4 n=10
Age (yrs)	37	47	37	41
Height (m)	1.80 ± 0.08	1.73 ± 0.04	1.73 ± 0.06	1.76 ± 0.06
Nude Weight (kg)	95.9 ± 11.6	78.3 ± 9.1	83.7 ± 17.0	87.2 ± 14.8
Dressed Weight (kg)	104.0 ± 10.1	88.0 ± 9.5	89.6 ± 17.5	95.3 ± 10.9
Difference (kg)	12.2 ± 7.3	9.6 ± 2.6	10.9 ± 1.0	12.1 ± 4.3
Siri (% body fat)	21.2 ± 5.0	18.8 ± 5.3	24.3 ± 7.3	21.4 ± 7.5
Brozek (%body fat)	20.8 ± 4.7	18.6 ± 4.9	23.7 ± 7.2	21.0 ± 6.9
Density ($kg \cdot m^{-3}$)	1.05 ± 0.01	1.06 ± 0.01	1.04 ± 0.01	1.05 ± 0.02
BSA (m^2)	2.2 ± 0.2	1.9 ± 0.1	2.0 ± 0.2	2.03 ± 0.2
BMI ($kg \cdot m^{-2}$)	29.6	26.1	27.9	28.2

Table 2. Average working depth and ambient conditions for each group

	Group 1 n=10	Group 2 n=9	Group 3 n=9	Group 4 n=10
Depth (m)	1652 ± 338	1813 ± 413	1623 ± 384	1838 ± 274
Temperature (°C)	23.9 ± 3.5	25.6 ± 4.2	22.5 ± 3.8	26.8 ± 2.3
Humidity (%RH)	63.7 ± 21.9	60.4 ± 16.4	67.3 ± 16.8	67.0 ± 3.5
Pressure (kPa)	116.4 ± 4.2	119.3 ± 6.8	118.9 ± 4.8	119.4 ± 3.8

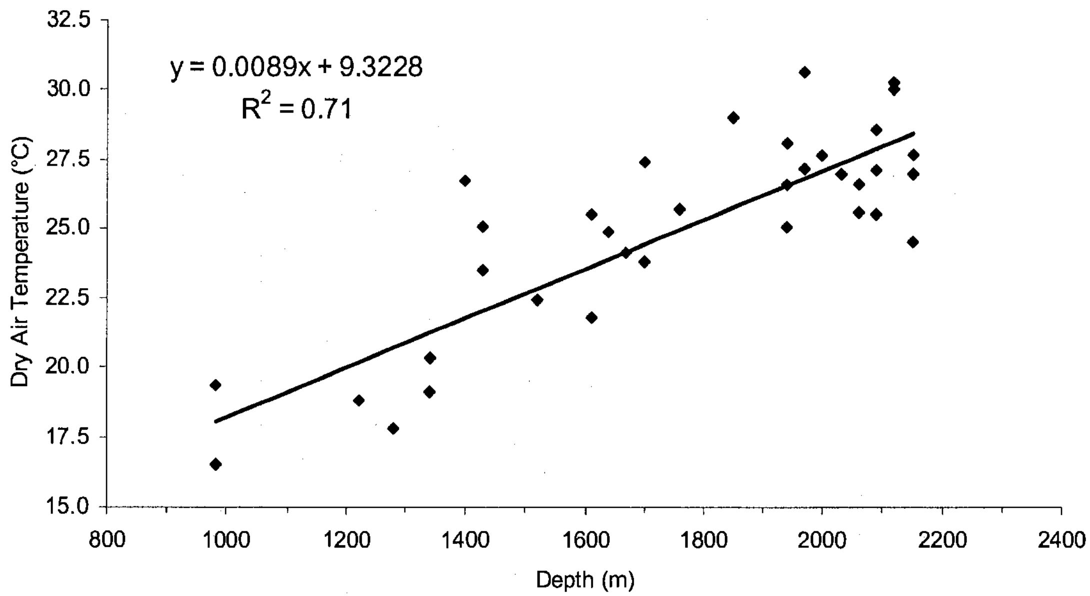

Figure 2. Average dry bulb temperature as a function of working depth experienced by the worker.

Appendix A: List of 23 identified common tasks performed in a mine from all work groups

1. Chipping: Picking at loose rock with an aluminum rod 2-3 m in length

2. Cutting: To cut a pipe, tubing or wire with a hand saw or pliers

3. Descending/Mounting: Climbing up or down a step ladder or machinery of 3-5 steps

4. Displacing: To push, carry, or move an object from one point to another

5. Drill and Pipe Maintenance: To change a drill bit or pipe

6. Driving: To guide, control, or direct a vehicle

7. Fencing: To bring and hold a metal screen against a rock face

8. Hammer and Anchor: Hammer: To hit with a hand held hammer or a metal rod Anchor: To hammer the anchor plate (flat metal square) and pipe combination to secure fencing in the rock face

9. Loading: To put an object (e.g. oil buckets, metal rods, etc.) into or onto a structure (e.g. truck) or to load pipe into drill carousel

10. Maintenance: To perform minor repairs of equipment or to clean up the work area and/or equipment

11. Miscellaneous: To perform various menial tasks e.g. shoveling, holding, etc.

12. Pipe Installation: To install/set up water pipe/hose

13. Preparation: To set up the working site, station or a checklist used for equipment before initializing work

14. Remote Control: To use a hand held joystick to control machinery. The operator may be sitting, standing, or walking while using the joystick

15. Setting Metal Rod: To insert a metal rod into a hole

16. Shotcrete: To spray cement with a pipe through a nozzle

17. Sitting: To sit in a chair or on the ground while resting or talking

18. Spraying: To spray water with hose or apply paint using spray can

19. Standing: Standing while writing, talking or waiting

20. Verification: Verifying blue prints by measuring distances, or proper functioning of equipment

21. Waiting: Remaining stationary. Combination of sitting or standing

22. Walking: Traveling on foot from one area to another with no load

23. Welding: To join or cut pieces of metal with electric or gas torch

Table 3. Significant differences observed between each group and their associated task during a work shift

Task	Groups 1 & 2	Groups 1 & 3	Groups 1 & 4	Groups 2 & 3	Groups 2 & 4	Groups 3 & 4
1		*		*		*
2						
3	*	*	*			
4					*	
5			*		*	*
6	**	**	**			
7						*
8	*	*	*			
9						
10						
11						
12	*	*		**	**	
13	*		*			
14		*				
15		*		*		*
16						
17						
18				*		
19						
20		**		**		**
21						
22						
23		*		*		*

* indicates significance at $p < 0.05$
** indicates significance at $p < 0.001$

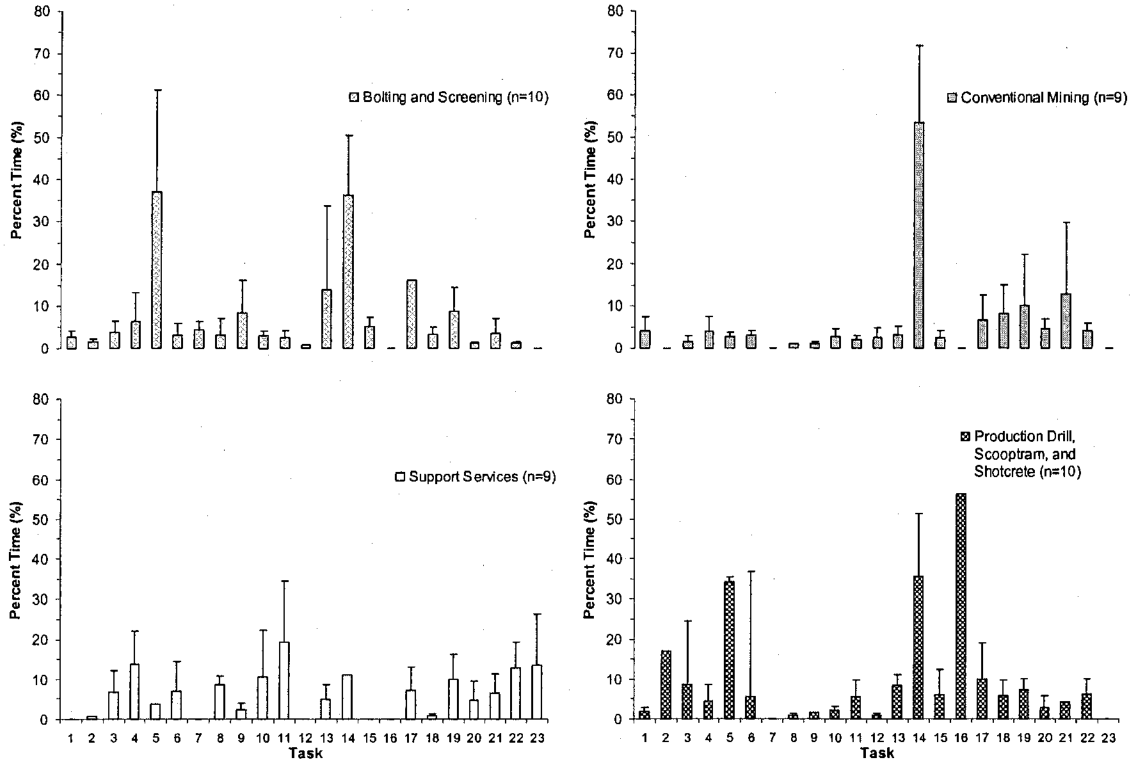

Figure 3. Percent time each group spent on the 23 identified tasks during a work shift.

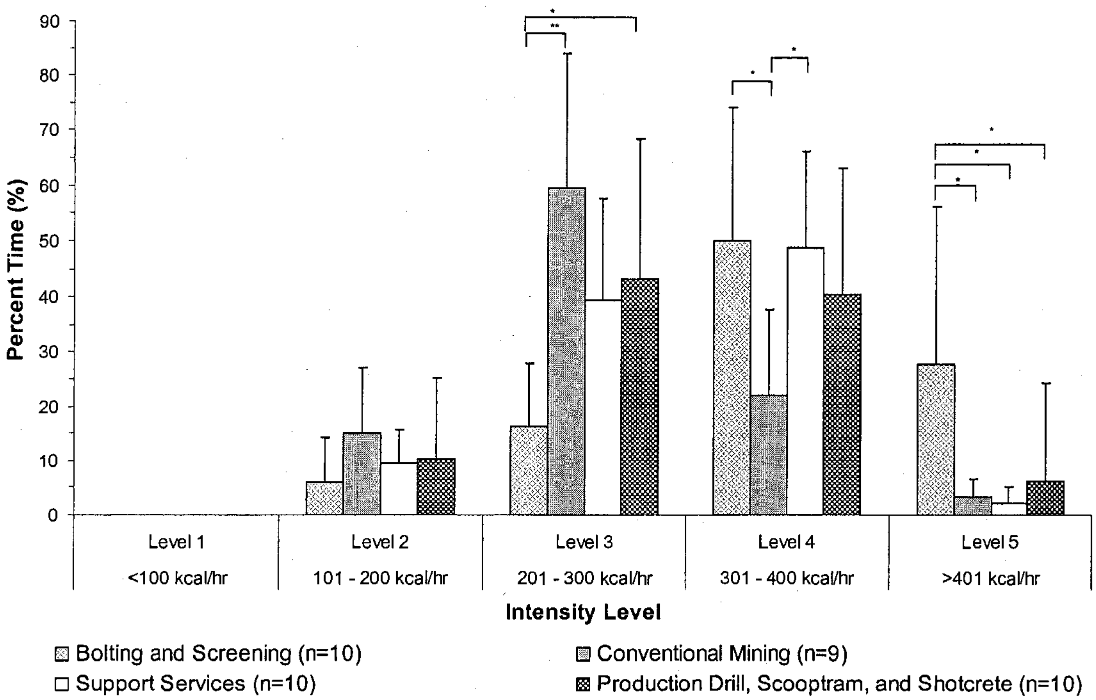

Figure 4. Subjective analysis of percent time spent at each intensity level according to work group
* indicates significance at $p < 0.05$
** indicates significance at $p < 0.001$

Table 4. Subjective analysis of energy expenditure for identified occupational tasks as determined by the AIHA

All Occupations	Average Task Intensity Level				
Task	Group 1	Group 2	Group 3	Group 4	All Groups
Chipping	4 - 5	3		4	4 - 5
Cutting	4			3 - 4	4
Descending Mounting	3 - 4	3	3 - 4	3 - 4	3 - 4
Displacing	4 - 5	3 - 4	3 - 5	4	3 - 5
Drill / Pipe Maintennance	3 - 5	3	3	4	3 - 5
Driving	3	3	3	3 - 4	4 - 5
Fencing	4 - 5				4 - 5
Hammer and Anchor	4 - 5	3 - 4	3 - 4	4	4 - 5
Loading	4 - 5	3	4	4	4 - 5
Maintenance	3 - 5	2 - 3	3 - 4	3 - 4	3 - 4
Miscellaneous	3 - 4	3	3 - 4	3 - 4	3 - 4
Pipe Installation	4	3		4	4
Preparation	4 - 5	2 - 3	3 - 4	3	3 - 5
Remote Control	3 - 5	2 - 3	3 - 4	3 - 4	3 - 4
Setting Metal Rod	3 - 5	4		4	3 - 5
Shotcrete				5	5
Sitting	2	2	2 - 3	2	2 - 3
Spraying	3 - 5	2 - 4	3	3 - 4	2 - 3
Standing	2 - 5	2 - 3	2 - 4	2 - 3	2 - 3
Verification	3	3 - 4	3	3	3 - 4
Waiting	3	2	2		2 - 3
Walking	2 - 4	2 - 3	2 - 4	3 - 4	3 - 4
Welding			4		4

Note: Level ratings of level 1 (<100 kcal/hr), level 2 (101 – 200 kcal/hr), level 3 (201 – 300 kcal/hr), level 4 (301 – 400 kcal/hr), level 5 (>401 kcal/hr) are in accordance with the AIHA intensity scale (1).

Acknowledgements

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CHAPTER IV

ARTICLE 2

Metabolic Analysis of Typical Mining Tasks in a Deep Canadian Mechanized Mine

by

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Abstract

The purpose of this study is to measure, in-situ, metabolic energy requirements through indirect calorimetry. Thirty nine subjects were divided into 4 groups based on typical Canadian mining jobs. These groups are: Group 1 (Bolting & Screening n=10), Group 2 (Conventional n=9), Group 3 (Support Services n=10), Group 4 (Production Drill n=4, Scooptram™ n=4 and Shotcrete n=3). Ambient working temperatures ranged between 26.8 ± 2.3°C to 22.5 ± 3.8°C; relative humidity 67.3 ± 16.8 % to 60.4 ± 16.8; atmospheric pressure 119.4 ± 3.8 kPa to 116.4 ± 4.2 kPa; depth 1838 ± 274 m to 1652 ± 338 m. These findings reveal similar rates of energy expenditure for all groups. There were no significant changes in deep tissue or skin temperatures. Changes in deep tissue temperature between baseline and post work period were 0.5 ± 0.2°K and 0.2 ± 0.2°K, with corresponding skin temperature changes of 0.8 ± 0.9°K and 1.2 ± 1.6°K. Given the occupations observed, under the current ambient conditions, miners do not appear to be in states of incompensable heat stress. Under more adverse conditions, if current practices are maintained, miners may be susceptible to heat stress related illnesses.

Keyword: Heat stress, WBGT, work intensity, body temperature, Canadian mine

Introduction

In industries such as mining and metal forging, workers are required to perform tasks which may expose them to adverse conditions. High thermal working conditions, in conjunction with high work loads, may increase the workers' risk of heat stress related injuries. This risk is directly related to the thermolytic (heat loss) capacity of the body under high heat load conditions.

Moreover, in the mining industry, it is progressively more costly to compensate for hot ambient conditions as the depth of mines continue to increase. These adverse conditions are the result of: increased rock face temperatures (RFT), venitlatory autocompression (26), and heat emission from mining equipment. High RFT and machinery temperatures consequently reduce or negate the capacity of the body to cool through radiation and conduction.

While the effect is minor, autocompression of ventilated air tends to decrease the vapour gradient necessary for efficient body heat loss by evaporation, relative to surface conditions. For example, in an Australian mine, at a high ambient wet bulb globe temperature (WBGT) of 29.0°C and barometric pressure of 110kPa (825 mmHg) (12), the calculated P_{H2O} is approximately 25.6 mmHg. Dehumidification/cooling of ventilated air are the primary means by which the cooling capacity of the worker is maintained.

The quantity of heat generated by increased metabolic activity (M) during work varies according to task (29) and intensity. Only a fraction, 20 to 30 % (37), of the metabolic energy is transferred into mechanical work (W). For example, a 400 W metabolic load may yield 280 to 380 W of heat production. This heat energy, if not dissipated from the body, is retained and tends to increase body heat storage which may raise the average body temperature.

Therefore, the relative rate of metabolic activity and net heat loss to the environment determine the rate of net heat exchange as indicated by S in the heat balance equation:

$$S = M \pm (R \pm C) \pm W - E$$

Where: S is the net heat gained (indicated by positive, negative, or zero)
M is the internal metabolic heat production
(R + C) is the net radiative and conductive heat exchange between the body surface and the environment
W is the mechanical work performed or done on the body
E is evaporative heat loss from the body surface including the pulmonary surface
*all units are expressed in Watts

Under high ambient conditions or under conditions where R + C is low or negative, then evaporation (E) becomes the primary means for thermolysis. The rate of E is modified by convective air flow over the exposed skin surfaces. Greater levels of convection increase the rate of heat energy exchange between body surfaces and the environment by E and C. In this case, sweating (E) provides the only means by which net heat transfer can occur. Under conditions where there is a low P_{H2O} gradient between the body and environment; i.e. when exposed body surface area is decreased, the overall rate of evaporative heat loss is reduced.

Mining apparel typically consists of: safety foot attire, long trousers, long sleeve shirt, and a safety helmet. With minimally exposed skin, thermolytic efficiency becomes reduced. In mining rescue personnel, thermolytic efficiency is further reduced by gloves, respirator/scrubber, and/or full fire retardant suits. As a result, these individuals have greatly reduced their heat loss capacity. Under the aforementioned conditions, there is a tendency towards net heat gain in the body which is manifested as a rise in Tpill.

Over the years, many heat stress indices have been developed to predict allowable heat exposure limits, which account for different variables in the heat balance equation (4, 21, 27). There are two general index types: 1) empirical, which attempt to predict the required cooling capacity for a worker based on meteorological conditions and 2) rational, which incorporates empirical and physiological variables. Of these two index types, it is the empirically based Wet

Bulb Glob Temperature (WBGT) that has gained general acceptance as a heat stress index within the Canadian mining industry (1).

A corrective extension to the WBGT is the threshold limit value (TLV). The TLV identifies specific work/rest ratios associated with certain metabolic energy expenditure levels to a corresponding WBGT. This extension attempts to reduce the probability that core temperature (Tc) will rise above 38°C (1). This index has specific metabolic intensity levels; however, it is only representative of generic tasks rather than to specific mechanized mining tasks with specified intensity levels. The shortcomings of the WBGT and the TLV are the fact they are *predictive* heat stress indices. These indices are designed for the general work populous but do not account for individual physiological differences. Various conditions such as diabetes (8), high adiposity (20), or cardiovascular disease (9) have been shown to alter thermoregulatory function. Since these predictive heat stress indices do not account for specific metabolic heat loads or the presence of confounding pathologies, there is an increased risk of exposing the worker to thermally stressful conditions.

Time motion analysis is a technique that characterizes task quantity, duration, and frequency, during specific work regimens. This technique has been extensively used to characterize sporting activities (10, 11, 28). Adapting this technique to the mining industry can be easily done to help characterize W in the aforementioned equation. Identifying W can resolve the M value. Differences in metabolic loads performed in common manual mining tasks have been identified (5, 14, 18, 25, 32, 36, 38).

Based on the conclusions of various authors, it can be induced that different heat loads are experienced by miners under the same work and environmental conditions. As a result of different tasks being performed and variations in metabolic heat loads, differences in the rate of net heat gain or loss can be estimated.

Metabolic heat load is often estimated using indirect open circuit calorimetry. This technique is based on measurements of volume and concentrations of oxygen and carbon dioxide in expired air. The efficiency of the human body and measurements of metabolic rate allow us to determine metabolic heat loads. In other words, metabolic heat load (M) component of the heat balance equation is then calculated.

An increase in Tc indicates a net heat gain. If this rise in heat gain is left uncompensated, then heat stress related illnesses may occur. Skin temperature is the cardinal factor in body heat loss and it determines, at any given time, the gradient between deep tissues and the periphery. This gradient is determined primarily by the quality of the external ambient environment. Hence, a reduced thermal gradient between the skin and the external environment will decrease the cooling capacity of the body through radiation and conduction.

Upon observation, mining occupations differ with task and intensity. Therefore, the purpose of this research is to measure the metabolic requirements for common mining occupations. Identifying these requirements can be used to distinguish occupations that are more metabolically taxing, which will enable the identification of occupations susceptible to heat stress related illnesses. The findings from the second phase of a multiphase project will be disseminated.

Methodology

The data collection for this study was carried out at the Agnico Eagle's Laronde mine in Northern Quebec over a period of 10 months. This investigation is an independent study which is part of a larger project. The protocol was approved by the University of Ottawa's research ethics board.

Thirty nine mining personnel participated in the study while carrying out three essential mining groups and one supplemental group. These groups were: Group 1 (Bolting & Screening (attaching steel mesh to walls and ceiling) n=10), Group 2 (Conventional Mining (using a hand-held drilling carriage to drills holes in rock walls and ceiling) n=9), Group 3 (Support Services (mechanic, welder, pipe layer) n=9), Group 4 (Production Drill (using a machine mounted drilling unit) n=4, Scooptram™ (ore transport with no air conditioner) n=4, and Shotcrete (concrete applied by spraying) n=3). All measurements were performed between the months of September 2005 to early June 2006.

Anthropometric measurements are given in table 1 and include: height, nude weight, and full work attire (subject's weight in addition to all equipment and water/lunch carried to the work site) weight. The quantity of food and water consumed throughout the day was not monitored. Skin fold measurements were taken in accordance with the ACSM (17) guidelines to determine body composition (6, 33). From these measurements, mean body density (15, 16, 22, 24, 34, 35, 39, 40) and body surface area (13) were calculated. All data was recorded and stored on a laptop (Panasonic Toughbook, CF-29, China).

Ambient conditions at each work site (ACR data logger Smart Reader 4, New Hampshire) (ACR) included: dry bulb (T_{db}), relative humidity, and ambient pressure. Three synchronized ACR units were used to record the ambient conditions continuously during the work shift. The first unit was located at one end of the subjects work site 1 to 2 m above the ground, the second unit was placed at abdominal level of the subject (~ 1 m above work platform), and the third unit was placed underneath the air duct supply 1 to 2 m above the ground. See Figure 1 for work site map.

In-situ analysis of oxygen consumption was performed using an open circuit portable ergospirometer (Jaeger, Oxycon Mobile, Germany). Deep tissue temperature (T_{pill}) was recorded continuously using an ingestible telemetric pill (Mini Mitter, Vital Sense, USA). The telemetric pill was administered to the subjects for ingestion using room temperature water approximately one and one half hours before descent. Mean skin temperature (13) of 10 skin sites was also estimated by the use of telemetric dermal sensors (Mini Mitter, Vital Sense, USA). These sensors were applied to the left side of the body: head temporal, trapezium, lumbar, bicep, triceps, forearm, pectoralis, abdominal, thigh, and calf.

Baseline metabolic energy expenditure was taken 15 min post instrumentation while sitting undisturbed in a quiet room; whereas deep tissue and skin temperatures were taken 15 min prior to entering the elevator shaft. Metabolic energy expenditure was measured throughout the entire work day along with deep tissue and skin temperatures.

Statistical Analysis

Work intensity groupings were evaluated according to the ISO 7243 standard in terms of intensity level 1 (0 to 65 $W \cdot m^{-2}$) level 2 (65 to 130 $W \cdot m^{-2}$), level 3 (130 to 200 $W \cdot m^{-2}$), level 4 (200 to 260 $W \cdot m^{-2}$), and level 5 (>260 $W \cdot m^{-2}$).

Metabolic data was analyzed using a One-Way ANOVA by employing the dependent variables of percentage of time spent at work intensity levels 1, 2, 3, 4, and 5 with the independent variable of job type group (levels: 1, 2, 3, and 4).

Deep tissue temperature and mean skin temperatures were averaged over 1 minute interval throughout the work shift. Baseline values were measured 15 min prior to the commencement of work. Peak 1, 10, and 30 min values were calculated by averaging temperatures consecutively elevated during the work shift.

Results

Ambient conditions observed for each group are indicated in table 2; group 4 observed to have the largest average dry bulb temperature (T_{db}) of 26.6 ± 2.1°C, while group 3 was observed with the lowest T_{db} of 24.0 ± 4.6°C. Relative humidity was similar between all groups, however, the smallest variation was experienced in group 4; 54.3 ± 5.3 %.

Using ISO 7243 categories for metabolic intensity levels, corrected for individual BSA, differences ($p<0.05$) in work intensity levels were observed between groups 3 and 4, at intensity level 4 (refer to figure 2). This level corresponds to an intensity of 200 to 260 $W \bullet m^{-2}$. No other statistical differences were observed between the groups and work intensity levels. However, large ranges were observed with respect to the durations spent at each of the intensity levels within each group. Total working time dedicated to higher intensity levels (levels 4 and 5), between all groups, was less then 15 % with the exception of Group 3, which accounted for 32 %. Though there was a noted difference in the time spent at the higher intensity levels (Group 3), there was large standard deviation in time allocation.

There were no significant changes in Tpill within and between groups. Table 3 identifies group 1 to have the highest post work Tpill of 37.8 ± 0.3°C, whereas Group 4 had the lowest (37.3 ± 0.2°C). All groups, with the exception of Group 4, had a 1 minute peak Tpill greater than 38°C; the 10 and 30 minute peak averages were less than this value.

Upon analysis of mean skin temperature, no statistical differences were identified between and within each group. Noteworthy was the change in Group 3, which showed a 2.1°C rise in temperature (table 4).

Discussion

This study showed variations in ambient conditions and metabolic energy expenditure levels. Even though differences were observed in working environment and metabolic intensity, there were no significant changes in deep tissue or mean skin temperatures.

According to the ISO 7243 guidelines, the ambient conditions measured do not appear to be stressful. Current mining practices entail deeper mines and warmer ambient conditions. It has been shown that the acclimation process typically occurs between 6 to 14 consecutive days of exposure (7, 23). This acclimation process become problematic for Canadian miners working during the winter months, as typical winter temperatures are well below T_{db} 0°C and typical mining conditions are approximately T_{db} 25°C or above. Thus, when returning to the surface under these conditions, the acclimation process will be inhibited.

A preventative measure needs to be implemented as problems maybe encountered in future mining endeavors. Acclimation becomes particularly important to individuals who have large body adiposity (2), older (3), dehydrated (19), or unacclimated (31). Greater heat loads may be experienced by these mining personnel, while working at the same intensity levels as healthy miners. Under stressful conditions and high metabolic levels, the cooling capacity for unacclimated miners may be inadequate and heat stress related illnesses are likely to occur. As noted by Senay (30), there is an acclimation protocol for South African laborers since these mines are known to be stressful. Given the aforementioned protocol, Canadian mines should implement a similar acclimation protocol.

According to ISO 7243, groups 1, 2, and 4 spent more time at intensity level 2 compared to other levels (figure 2). Group 3 was observed to have spent almost equal amount of time in intensity levels 2 and 3 (39 and 47 % respectively). Literature has shown metabolic energy expenditure requirements to work in a UK pot-ash mine to range between 274 W and 470W (36). Assuming a BSA of 2 m^2, the corresponding work intensities would be approximately 137 Wm^{-2} and 235 Wm^{-2}, which corresponds to levels 3 and 4, respectively. It would appear that pot-ash miners work at higher intensity levels than Canadian mechanized miners. Despite the higher work intensity, it is important to note that both UK and Canadian miners work at different ranges of metabolic intensities. Therefore, to allocate one intensity level would not adequately represent the mining occupation.

Our observations showed no differences in intensity levels in any of the groups, except for groups 3 and 4 at level 4. The variability of metabolic energy expenditures within each group identified the unique requirements within each occupation. One possible explanation for within group variability is rock type, which can change, depending on the area within the mine. Under adverse ambient conditions, given the current metabolic data, this would suggest groups those groups who work at higher work intensities for longer larger periods, such as group 3, are more susceptible to heat stress related illnesses.

A net gain of heat by the body is reflected as an increase in T_c. Changes in Tpill were measured from baseline to post work period, peaks for 1, 10, and 30 min. No significant changes were observed in Tpill between baseline and post work period. Further investigation of Tpill identified that the averaged 10 and 30 min peak temperatures were lower then the recommended ACGIH (1) value of 38°C. However, there were episodes where minute peak temperatures reached values greater than 38°C for three of the four groups. Under current ambient conditions, our results indicate that there is adequate cooling capacity for the miners to regulate their body temperature.

No significant changes in mean skin temperatures identified in this study. Further analysis of mean skin temperature, (table 4) during the same episodes of 10 and 30 min, revealed that these values were less than body temperature. This observation supports our previous conclusion that miners have adequate cooling capacity.

Conclusion

The present study showed similar metabolic energy expenditures between the different mining groups; however, the intensities of the tasks performed within each group differed. Changes in deep tissue and mean skin temperatures did not significantly elevate from baseline values, even though 1 min peak Tpill values were greater compared to 10 and 30 min mean peak values.

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Figure 1. Sketch of a work site and location of instruments used by the investigators in relation to the worker

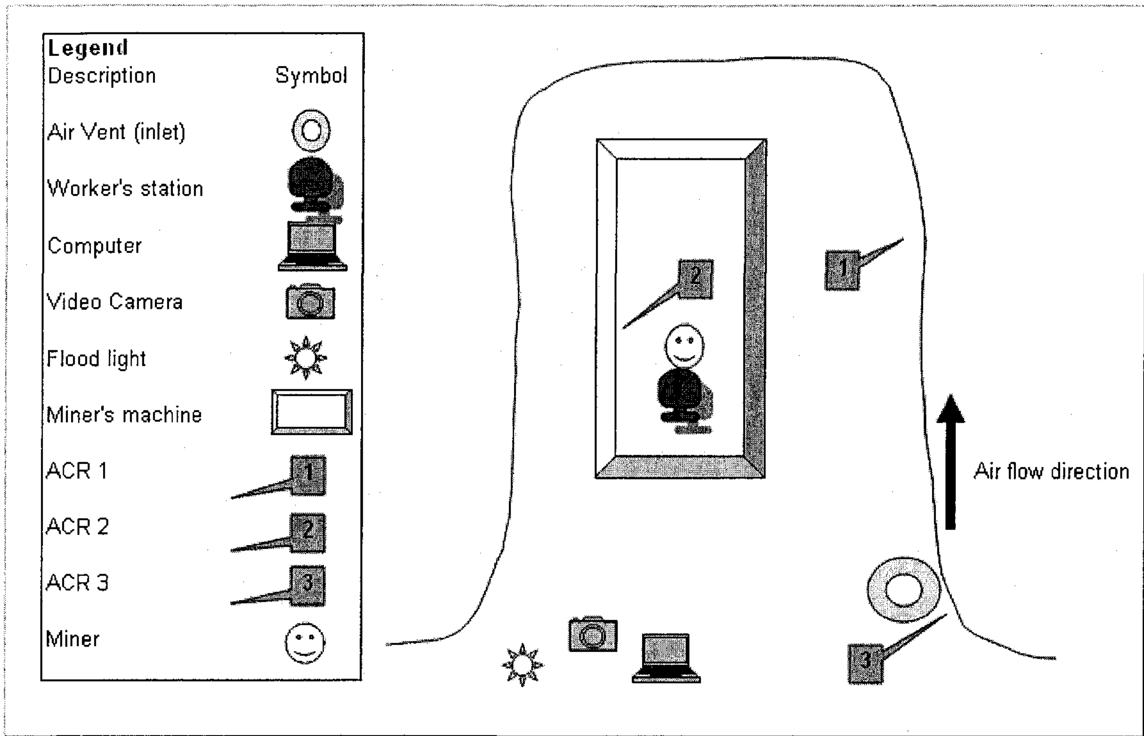

Table 1. Anthropometric data for each group for part 1 of the study

	Group 1 n=10	Group 2 n=9	Group 3 n=10	Group 4 n=10
Age (yrs)	38	48	38	42
Height (m)	1.80 ± 0.08	1.73 ± 0.04	1.73 ± 0.06	1.76 ± 0.06
Nude Weight (kg)	95.9 ± 11.6	78.3 ± 9.1	83.7 ± 17.0	87.2 ± 14.8
Dressed Weight (kg)	104.0 ± 10.1	88.0 ± 9.5	89.6 ± 17.5	95.3 ± 10.9
Difference (kg)	12.2 ± 7.3	9.6 ± 2.6	10.9 ± 1.0	12.1 ± 4.3
Siri (% body fat)	21.2 ± 5.0	18.8 ± 5.3	24.3 ± 7.3	21.4 ± 7.5
Brozek (%body fat)	20.8 ± 4.7	18.6 ± 4.9	23.7 ± 7.2	21.0 ± 6.9
Density ($kg \cdot m^{-3}$)	1.05 ± 0.01	1.06 ± 0.01	1.04 ± 0.01	1.05 ± 0.02
BSA (m^2)	2.2 ± 0.2	1.9 ± 0.1	2.0 ± 0.2	2.03 ± 0.2
BMI ($kg \cdot m^{-2}$)	29.6	26.1	27.9	28.2

Table 2. Average working depth and ambient conditions for each group

	Group 1 n=7	Group 2 n=8	Group 3 n=9	Group 4 n=9
Ambient Temp (°C)	25.6 ± 2.6	26.5 ± 1.3	24.0 ± 4.6	26.6 ± 2.1
Ambient RH (%)	67.2 ± 17.5	66.3 ± 22.8	55.9 ± 25.2	54.3 ± 5.3
Ambient Press (kPa)	116.5 ± 7.3	119.3 ± 6.1	114.3 ± 4.9	119.7 ± 2.8
WBGT (°C)	23.8 ± 2.2	23.1 ± 1.5	25.7 ± 1.3	23.8 ± 1.8

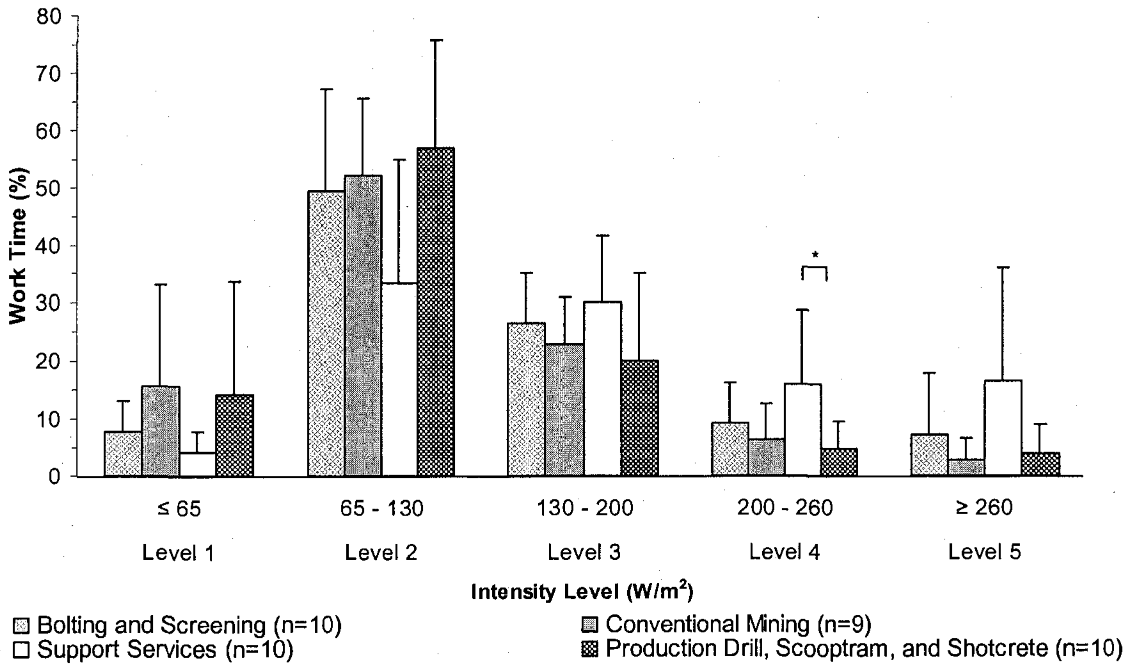

Figure 2. Work time (%) in percent spent at each of the five ISO 7243 work intensity levels during a work shift.
*notes a significance ($P < 0.05$)

Table 3. Baseline, end of shift, 1, 10, and 30 min peak average measurement values for deep tissues temperature (°C)

	Group 1 n=6	Group 2 n=8	Group 3 n=9	Group 4 n=9
Baseline	36.9 ± 0.3	37.1 ± 0.1	37.1 ± 0.3	37.0 ± 0.3
Work	37.8 ± 0.3	37.4 ± 0.2	37.4 ± 0.2	37.3 ± 0.2
Peak 1 min	38.3	38.3	38.1	37.9
Peak 10 min	37.8 ± 0.3	37.7 ± 0.2	37.7 ± 0.2	37.8 ± 0.2
Peak 30 min	37.8 ± 0.3	37.7 ± 0.2	37.7 ± 0.2	37.8 ± 0.2

Table 4. Baseline, end of shift, 1, 10, and 30 min peak average measurement values for mean skin temperature (°C)

	Group 1 n=2	Group 2 n=8	Group 3 n=4	Group 4 n=7
Baseline	33.2 ± 0.6	31.9 ± 1.2	30.8 ± 1.2	32.1 ± 0.8
Work	34.0 ± 0.3	32.9 ± 1.4	32.9 ± 1.4	33.7 ± 0.8
Peak 1 min	34.9	35.5	36.2	34.9
Peak 10 min	34.3 ± 0.4	33.7 ± 1.2	34.3 ± 1.1	34.3 ± 1.3
Peak 30 min	34.4 ± 0.3	33.7 ± 1.2	34.0 ± 1.3	34.2 ± 1.3

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CHAPTER V

DISCUSSION

5.0 Discussion

Canadian mining personnel are exposed to adverse conditions and heavy work loads each day. It is currently unknown whether all common mining jobs in this mine are exposed to similar environmental and physical stressors. The focus of this thesis was to provide insight into the tasks and physiological demands placed on miners in a deep Canadian mechanized mine.

In our first study, we examined the ergonomics and the ambient working conditions associated with deep mechanized mining. Through our observations, we identified 23 common tasks which were performed by four different occupational groups. The duration and frequency of these tasks varied according to each mining group. Time motion analysis identified that certain tasks were performed more frequently by specific groups. This identifies the unique role of each group, which revealed a disproportionate amount of time being dedicated to certain tasks. Upon subjective analysis, it was identified that certain groups worked at higher intensities then others. This can be attributed to the unique requirements of each group. From our observations we conclude that there are large variations of tasks and work intensities between and within each of the common mining groups. Literature supports our findings of variations in work tasks and intensities in a mine (Sieber 1963; Leithead 1964; Williams, Wyndham et al. 1968; Bethea 1980; Graves, Leamon et al. 1981; Weller 1981). In part one; our findings suggest a more objective investigation of mining groups' energy requirements is required.

Part two of the study focused on the metabolic requirements and the physiological responses of work in each group. Our observations revealed significant differences ($p<0.05$) between one pair of mining groups at level 4 metabolic energy expenditure intensity level, as designated by ISO 7243. Noteworthy are the metabolic variations observed within each group. Variations in energy expenditure can be attributed to the different tasks performed and/or job requirements, as identified in part 1. Work rates did not produce a significant change in deep tissue or skin temperatures, even though there was a small rises in T_c. Upon analysis of T_c during 1, 10, and 30 min averaged peaks, it was observed that the 1 min peak was larger than the 10 and 30 min peaks. This demonstrates that peak rises in T_c are acute.

Economic incentives to mine deeper are more prevalent. As a result, an associated increase in the geothermal gradient and ventilatory autocompression accompany these practices, all of which expose miners to greater potential heat loads. Increasing ambient conditions, in conjunction with heavy work loads, can expose the miner to incompensable heat loads. The overall net heat gain will eventually lead to heat stress related illnesses. Other factors that may exacerbate the rate of net heat storage during work are: hydration of mining personnel, acclimation status, personal protective equipment, proximity to heavy machinery, and overall health of the miners. These factors have been known to influence the rate of heat storage. Therefore, special focus should be placed on these variables while working in a deep mechanized mine as work regimens vary in intensity.

5.1 Conclusion & Recommendations

Deep Canadian mechanized mine workers perform specific tasks, which are the result of unique occupational requirements. Despite these requirements, metabolic energy expenditures were found to be similar; no net heat was gained by the worker during labor, given no significant changes in T_c. Though the study was conducted under non-stressful conditions, future investigations should focus on the effects of stressful ambient conditions during work, which may influence work intensities and heat regulation.

Since heat stress related illnesses are the result of the thermolytic systems inability to balance heat loads, it would be ideal to identify when system failure may potentially occur. Through laboratory simulations, as measured in-situ, work markers could be used to help identify the potential onset of such a failure. If this marker is identified, the worker can safely be removed from the working environment, prior to the onset of illness. If a miner is fully hydrated, acclimated, medically healthy, and young, then they are in a favourable position for regulating heat in the mining environment. Typically miners are not of this profile. However, within these factors, hydration has been found to play a significant role in thermoregulation (Nadel, Bullard et al. 1971; Gisolfi and Copping 1974; Cheuvront and Haymes 2001; Moran and Mendal 2002). Therefore, to ensure a safe work environment, it is important for the miners to be aware of the effects of dehydration and the symptoms for the onset of heat related illnesses.

The work presented gives future investigators the background ergonomic information to generate correction factors to existing heat stress indices. These corrections can apply, not only, to the mining industry but also to those industries where workers are continually exposed to high ambient conditions and work intensities, such as steel mills/ foundries, factories, or the military.

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APPENDIX A

A.1 Physical Activity Readiness Questionnaire (Par-Q)

A.2 Letter of Information and Recruitment Text

A.3 Background Information and Informed Consent Form

A.1: Physical Activity Readiness Questionnaire (Par-Q)

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q:</u> The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________________ DATE ________________________

SIGNATURE OF PARENT ________________________________ WITNESS ________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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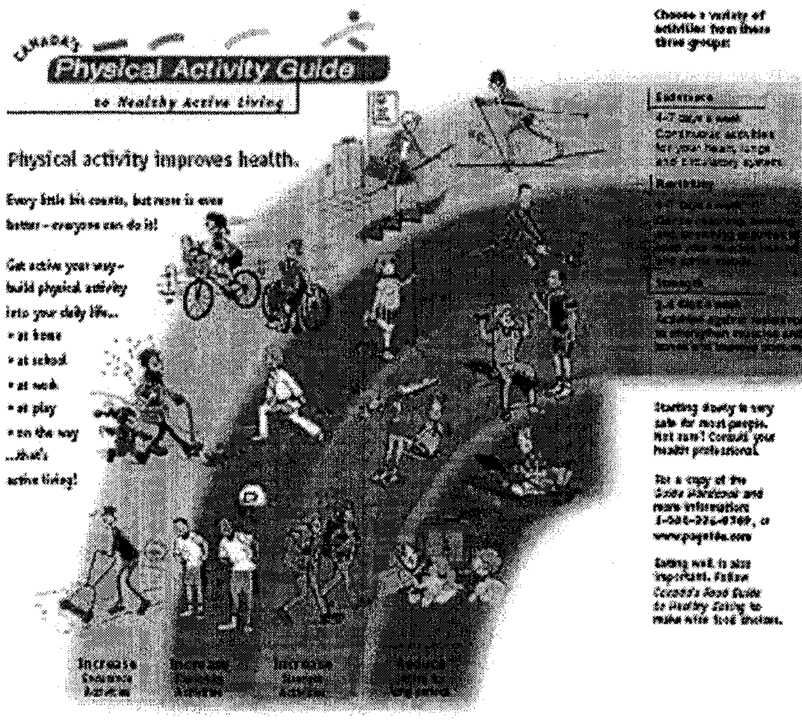
PAR-Q & YOU

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)



Get Active Your Way, Every Day—For Life!

Scientists say accumulate 60 minutes of physical activity every day to stay healthy or improve your health. As you progress to moderate activities you can cut down to 30 minutes, 4 days a week. Add-up your activities in periods of at least 10 minutes each. Start slowly... and build up.

Time needed depends on effort

Range needed to stay healthy

Physical activity doesn't have to be very hard. Build physical activities into your daily routine.

- Walk whenever you can—get off the bus early, use the stairs instead of the elevator.
- Reduce inactivity for long periods, like watching TV.
- Get up from the couch and stretch and bend for a few minutes every hour.
- Play actively with your kids.
- Choose to walk, wheel or cycle for short trips.
- Start with a 10 minute walk—gradually increase the time.
- Find out about walking and cycling paths nearby and use them.
- Observe a physical activity class to see if you want to try it.
- Try one class to start—you don't have to make a long-term commitment.
- Do the activities you are doing now, more often.

Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf

FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The Physical Activity Readiness Medical Examination (PARmed-X) — to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy) — to be used by doctors with pregnant patients who wish to become more active.

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For more information, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 2002)».

Questionnaire sur l'aptitude à l'activité physique - Q-AAP (version révisée en 2002)

Q-AAP et VOUS

(Un questionnaire pour les gens de 15 à 69 ans)

L'exercice physique pratiqué d'une façon régulière constitue une occupation de loisir saine et agréable. D'ailleurs, de plus en plus de gens pratiquent une activité physique de façon régulière. Règle générale, augmenter la pratique sportive n'entraîne pas de risques de santé majeurs. Dans certains cas, il est cependant conseillé de passer un examen médical avant d'entreprendre un programme régulier d'activités physiques. Le Q-AAP (questionnaire sur l'aptitude à l'activité physique) vise à mieux cerner les personnes pour qui un examen médical est recommandé.

Si vous prévoyez modifier vos habitudes de vie pour devenir un peu plus actif(ve), commencez par répondre aux 7 questions qui suivent. Si vous êtes âgé(e) de 15 à 69 ans, le Q-AAP vous indiquera si vous devez ou non consulter un médecin avant d'entreprendre votre nouveau programme d'activités. Si vous avez plus de 69 ans et ne participez pas d'une façon régulière à des activités physiques exigeantes, vous devriez consulter votre médecin avant d'entreprendre ces activités.

Lisez attentivement et répondez honnêtement à chacune des questions suivantes. Le simple bon sens sera votre meilleur guide pour répondre correctement à ces questions. Cochez OUI ou NON.

OUI	NON	
☐	☐	**1. Votre médecin vous a-t-il déjà dit que vous souffriez d'un problème cardiaque <u>et</u> que vous ne deviez participer qu'aux activités physiques prescrites et approuvées par un médecin?**
☐	☐	**2. Ressentez-vous une douleur à la poitrine lorsque vous faites de l'activité physique?**
☐	☐	**3. Au cours du dernier mois, avez-vous ressenti des douleurs à la poitrine lors de périodes autres que celles où vous participiez à une activité physique?**
☐	☐	**4. Éprouvez-vous des problèmes d'équilibre reliés à un étourdissement ou vous arrive-t-il de perdre connaissance?**
☐	☐	**5. Avez-vous des problèmes osseux ou articulaires (par exemple, au dos, au genou ou à la hanche) qui pourraient s'aggraver par une modification de votre niveau de participation à une activité physique?**
☐	☐	**6. Des médicaments vous sont-ils actuellement prescrits pour contrôler votre tension artérielle ou un problème cardiaque (par exemple, des diurétiques)?**
☐	☐	**7. Connaissez-vous <u>une autre raison</u> pour laquelle vous ne devriez pas faire de l'activité physique?**

Si vous avez répondu

OUI à une ou plusieurs questions

Consultez votre médecin AVANT d'augmenter votre niveau de participation à une activité physique et AVANT de faire évaluer votre condition physique. Dites à votre médecin que vous avez complété le questionnaire sur l'aptitude à l'activité physique et expliquez-lui précisément à quelles questions vous avez répondu «OUI».

- Il se peut que vous n'ayez aucune contre-indication à l'activité physique dans la mesure où vous y allez lentement et progressivement. Par ailleurs, il est possible que vous ne puissiez faire que certains types d'efforts adaptés à votre état de santé. Indiquez à votre médecin le type d'activité physique que vous comptiez faire et suivez ses recommandations.
- Informez-vous quant aux programmes d'activités spécialisés les mieux adaptés à vos besoins, offerts dans votre localité.

NON à toutes ces questions

Si, en toute honnêteté, vous avez répondu «NON» à toutes les questions du Q-AAP, vous êtes dans une certaine mesure, assuré(e) que:

- vous pouvez augmenter votre pratique régulière d'activités physiques en commençant lentement et en augmentant progressivement l'intensité des activités pratiquées. C'est le moyen le plus simple et le plus sécuritaire d'y arriver.
- vous pouvez faire évaluer votre condition physique. C'est le meilleur moyen de connaître votre niveau de condition physique de base afin de mieux planifier votre participation à un programme d'activités physiques.

→ **REMETTRE À PLUS TARD L'AUGMENTATION DE VOTRE PARTICIPATION ACTIVE:**

- si vous souffrez présentement de fièvre, d'une grippe ou d'une autre affection passagère, attendez d'être remis(e); ou
- si vous êtes enceinte ou croyez l'être, consultez votre médecin avant de modifier votre niveau de pratique sportive régulière.

Veuillez noter que si votre état de santé se trouve modifié de sorte que vous deviez répondre «OUI» à l'une ou l'autre des questions précédentes, consultez un professionnel de la santé ou de la condition physique, afin de déterminer s'il vous faut modifier votre programme d'activités.

<u>Formule de consentement du Q-AAP</u>: La Société canadienne de physiologie de l'exercice, Santé Canada et ses représentants n'assument aucune responsabilité vis-à-vis des accidents qui pourraient survenir lors de l'activité physique. Si, après avoir complété le questionnaire ci-dessus, un doute persiste quant à votre aptitude à faire une activité physique, consultez votre médecin avant de vous y engager.

Toute modification est interdite. Nous vous encourageons à copier le Q-AAP dans sa totalité.

Dans la mesure où le Q-AAP est administré avant que la personne ne s'engage dans un programme d'activités ou qu'elle fasse évaluer sa condition physique, la section suivante constitue un document ayant une valeur légale et administrative.

«Je sous-signé(e) affirme avoir lu, compris et complété le questionnaire et avoir reçu une réponse satisfaisante à chacune de mes questions.»

NOM ______________________________

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE D'UN PARENT ______________________________ TÉMOIN ______________________________
ou TUTEUR (pour les mineurs)

N.B.— Cette autorisation de faire de l'activité physique est valide pour une période maximale de 12 mois à compter du moment où le questionnaire est rempli. Elle n'est plus valide si votre état de santé change de telle sorte que vous répondez «OUI» à l'une des sept questions.

suite au verso...

...suite

Q-AAP et VOUS

Questionnaire sur l'aptitude à l'activité physique - Q-AAP (version révisée en 2002)

Source: Guide d'activité physique canadien pour une vie saine, Santé Canada, 1998 http://www.hc-sc.gc.ca/hppb/guideap/pdf/guidefre.pdf.

AUX PROFESSIONNELS DE LA CONDITION PHYSIQUE ET DE LA SANTÉ :

Les formulaires complémentaires suivants sont aussi disponibles. Veuillez consulter notre site web à l'adresse : http://www.csep.ca/formulaires.asp.

L'Évaluation médicale de l'aptitude à l'activité physique (PARmed-X). Formulaire conçu pour le médecin traitant de la personne ayant répondu "OUI" à au moins une des questions du Q-AAP.

L'Évaluation médicale de l'aptitude à l'activité physique pour la grossesse (PARmed-X pour femmes enceintes). Formulaire conçu pour le médecin dont les patientes enceintes veulent faire de l'activité physique.

Références :

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health.** Champaign, IL: Human Kinetics.

PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

Pour télécharger les copies additionnels, veuillez consulter notre site web: http://www.csep.ca/formulaires.asp. Pour plus d'informations veuillez contacter la :

Société canadienne de physiologie de l'exercice
202-185 rue Somerset Ouest
Ottawa (Ontario) CANADA K2P 0J2
Tél. (sans frais) 1-877-651-3755 • Téléc. (613) 234-3565
Site web : www.csep.ca

Le Q-AAP original a été conçu par le ministère de la Santé de la Colombie-Britannique. Il a été révisé par les membres d'un Comité consultatif d'experts de la Société canadienne de physiologie de l'exercice sous la direction du Dr N. Gledhill (2002).

Available in English under the title: "Physical Activity Readiness Questionnaire - PAR-Q and YOU (revised 2002)"

Avec l'appui de: Santé Canada Health Canada

A.2: Letter of Information and Recruitment Text

Heat stress in Canadian, deep, mechanized mines: Personnel heat exposure issues.

Good afternoon. First of all I would like to thank you for your attendance at this presentation. I am *(Reardon, or Kenny)* from the J.W. Snellen Memorial Laboratory at the University of Ottawa, School of Human Kinetics. We have been working in close collaboration with the Canadian Mining Industry Research Organization (CAMIRO) and the Deep Mining Research Consortium (DMRC) to conduct research on the effects of heat exposure on workers in deep mines. The ultimate goal of this research is to evaluate the current worker safety standards as they apply to heat exposure in Canada's deep mines. There is an increasing need to control heat exposure of personnel working in mines as the ambient temperature in the working environment appears to increase as a function of the depth of the mine. This issue is becoming increasingly important to the extent that it may become the overriding criterion in ventilation system design. Therefore ways must be sought through research focused on optimizing worker safety, to prolong the viability of deep mines in particular and in general, the northern economies that they support. Additionally, the optimization of power usage either in ventilation or refrigeration would benefit Canada as a whole through reduced, greenhouse gas emissions.

Currently, mining work standards for environmental temperatureare based more on the quality of the ambient physical conditions than they are on the effect those conditions may have on the individual miner. Further, these standards were developed from observations in mines that are fundamentally different from deep mechanized mines in Canada.

The purpose of this study, as the first phase of an on-going and more extensive project, is to investigate the role of work rate and body heat production and on heat storage in workers in deep, mechanized mines.

Specifically, this project is composed of two phases that will be carried out consecutively. The object of the first phase is to mechanically characterize various, common tasks that miners undertake during normal mining practice. The second phase is designed to evaluate the energy cost, and therefore the heat generated and stored by the miner, in carrying out these tasks during the full work shift. As such, they will not be done under extreme conditions of temperature but rather in relatively normal mining conditions. Note that these studies are more observational in nature in that they are designed to monitor the miners under normal working conditions. Thus the first phase will consist of i) video-recording the miners as they perform selected tasks during a 6 hour work period, and ii) doing a time/motion analysis of the task based on these recordings. The second phase will consist of monitoring these very same miners for body temperature changes and energy cost, while performing these tasks.

As a subject, you would be asked to participate in two sessions: the first during which you will be recorded on video during a 6 hour period as you work at your normal daily tasks; during the second session you will be asked to wear a snugly fitting face mask and breathe through a one way non-rebreathing valve. Your expired gas will be collected and analyzed for volume and oxygen

(O_2) and carbon dioxide (CO_2) composition using a portable automated metabolic analyzer (Sensor-Medics, Quinton, Seattle, USA). The analyzer is carried in a small dorsal pack under your outer clothing layer. Your expired gas will be sampled for 30 minutes, 4 times during a 6 hour period.

As well, you will be fitted with either an esophageal, rectal, tympanic or gastric temperature sensor and 12 skin surface sensors. The esophageal and rectal temperatures will be recorded using a pediatric esophageal temperature probe, (2 mm diameter), respectively inserted i) through your nostril to a depth that places the tip at the level of your heart, equal to one quarter of your standing height, or ii) into the rectum to a depth of 20 cm. For tympanic temperature recording a soft, fine wire, tympanic probe is inserted by the subject into her/his ear canal to a depth such that the tip of the probe is approximately 1 mm from the ear drum (≅ 1.5cm). It is secured in place by packing the canal with cotton batting. The gastric temperature is measured by having the subject swallow a small radio transmitter "pill" that transmits the temperature as the "pill" moves through the intestinal tract. The "pill" is naturally eliminated during the bowel movement 24 – 48 hours later. The transmitter pills are disposable and not recycled. The signal, like those of the esophageal, rectal and tympanic probes is captured and recorded in the portable data logger carried in a small back pack under your outer clothing layer.

Your skin temperature will be monitored at 12 sites on the skin surface and the mean skin temperature will be calculated. These surface probes (Concept Engineering, Old Saybrook, CT) are fixed to the skin surface using hypoallergenic, double sided tape at 12 specific sites: forehead (1), neck (1), back (2), chest (2), forearms (2), thighs (2) and calves(2). These as well, are directly connected to the portable data logger, as above. Data will be recorded for 6 hours during your work shift.

If you agree to participate in this project, you will be given a copy of this background information and a consent form to sign and return at your leisure, indicating your willingness to participate.

Your participation in this research project is entirely voluntary and you may refuse to participate or withdraw from the study at any time without adverse consequence. If you have any further questions regarding this project or the nature of the protocol, at any time before, during or after your consenting to participate, please contact:

Prof. Francis D. Reardon
School of Human Kinetics
Faculty of Health Sciences
University of Ottawa
Ottawa, Ontario
K1N 6N5, Canada
Email: freardon@uottawa.ca
Phone: (613) 562-5800 x4270
Fax: (613) 562-5149

Prof. Glen P. Kenny
School of Human Kinetics
Faculty of Health Sciences
University of Ottawa
Ottawa, Ontario
K1N 6N5, Canada
Email: gkenny@uottawa.ca
Phone: (613) 562-5800 x4282
Fax: (613) 562-5149

A.3: Background Information and Informed Consent Form

BACKGROUND INFORMATION AND CONSENT OF THE SUBJECT

Heat stress in Canadian, deep, mechanized mines: Personnel heat exposure issues.

Principle Investigator: Francis D. Reardon
Co-Investigator: Glen P. Kenny
J.W. Snellen Memorial Laboratory
University of Ottawa, School of Human Kinetic

INTRODUCTION

The University of Ottawa has been working in close collaboration with the Canadian Mining Industry Research Organization (CAMIRO) and the Deep Mining Research Consortium (DMRC) to conduct research on the effects of heat exposure on workers in deep mines. The ultimate goal of this research is to evaluate the current worker safety standards as they apply to heat exposure in Canada's deep mines. There is an increasing need to control heat exposure of personnel working in mines as the ambient temperature in the working environment appears to increase as the mine gets deeper. This issue is important because it affects the fundamental design of the ventilation system. Consequently, due to the high cost of ventilation and refrigeration control systems, heat exposure and worker security issues eventually will limit the depth to which Canada's existing mines remain operational. Thus, potentially rich ore reserves may not be mined. Therefore ways must be sought through research focused on optimizing worker safety, to prolong the productivity of deep mines in particular and in general, the northern economies that they support. Additionally, the optimization of power usage either in ventilation or refrigeration would benefit Canada as a whole through reduced, greenhouse gas emissions.

Currently, mining work standards for environmental temperature are based more on the quality of the physical environmental conditions than they are on the effect of those conditions on the individual miner. Further, these standards were developed from observations in mines that are fundamentally different from deep mechanized mines in Canada.

The purpose of this study, as the first phase of an on-going and more extensive project, is to investigate the role of work rate and body heat production on heat storage in mine workers. Specifically, this project is composed of two phases that will be carried out consecutively. The object of the first phase is to mechanically evaluate various common tasks that miners undertake during normal mining practice. The second phase is designed to evaluate the energy cost, and therefore the heat generated and stored by the miner, in undertaking these tasks during the full work shift. As such, the evaluations will not be done under extreme conditions of temperature but rather in relatively normal mining conditions. Note that these studies are more observational in nature in that they are designed to monitor the miners under normal working conditions. Thus the first phase will consist of i) video-recording the miners as they perform selected tasks during a 6 hour work period, and ii) doing a time/motion analysis of the task based on these recordings. The second phase will consist of monitoring these very same miners for body temperature changes and energy cost, while performing the same tasks.

INFORMATION

As a subject, you will be asked to participate in two 6 hour sessions: the first during which you will be recorded on video for a 6 hour period as you work at your normal daily tasks; during the second session you will be asked to wear a snugly fitting face mask and breathe through a one way non-rebreathing valve. Your expired gas will be collected and analyzed for volume and oxygen (O_2) and carbon dioxide (CO_2) composition using a portable automated metabolic analyzer (Sensor-Medics, Quinton, Seattle, USA). The analyzer is carried in a small dorsal pack under your outer clothing layer. Your expired gas will be sampled for 30 minutes, 4 times during the 6 hour period.

As well, you will choose to be fitted with either an esophageal, rectal, ear canal or stomach temperature sensor and 12 skin surface sensors. The esophageal and rectal temperatures will be recorded using a fine esophageal temperature probe, (2 mm diameter), respectively inserted i) through your nose to a depth that places the tip at the level of your heart, equal to one quarter of your standing height, or ii) into the rectum to a depth of 20 cm. For ear canal temperature recording a soft, fine wire, tympanic probe is inserted by the subject into her/his ear canal to a depth such that the tip of the probe is approximately 1 mm from the ear drum (≅ 1.5cm). It is secured in place by packing the canal with cotton batting. The stomach temperature is measured by having the subject swallow a small radio transmitter "pill" that transmits the temperature as the "pill" moves through the stomach and intestines. The "pill" is naturally eliminated during the bowel movement 24 – 48 hours later. The transmitter pills are disposable and not recycled. The signal, like those of the esophageal, rectal and ear canal probes is captured and recorded in the portable data logger carried in a small back pack under your outer clothing layer.

Your skin temperature will be monitored at 12 sites on the skin surface and the mean skin temperature will be calculated. These surface probes (Concept Engineering, Old Saybrook, CT) are fixed to the skin surface using hypoallergenic, double sided tape at 12 specific sites: forehead (1), neck (1), back (2), chest (2), forearms (2), thighs (2) and calves(2). These as well, are directly connected to the portable data logger, as above. Data will be recorded for 6 hours during your work shift.

There is negligible risk of physical harm or inconvenience associated with the filming procedures in the first phase of this study. However during the second phase, while recording the different body temperatures and the oxygen consumption, there is some risk of minor irritation associated with the placement of the temperature probes on the skin and in the esophagus, rectum or ear canal. In general these risks are considered to be minimal.

There will be no direct benefit to you from these procedures or from your participation in this study. However, the investigators may learn about the energy cost of mine work and will share these results at the end of the study, upon your request.

Your anonymity is ensured as much as is possible during filming at 20-30 feet distance (in dark mining conditions) and, by the assigning of number codes to subjects by the investigators.. Only pooled data will be published and you will not be identified in any written reports or publications.

Confidentiality will be ensured to the extent that raw data will be seen only by the investigators and research/technical personnel. Data will be stored on a single computer (locked - with limited access) in a secure laboratory in Montpetit Hall at the University of Ottawa. Hardcopy (video recordings and data sheets) data will be stored in a locked cabinet in the office of Francis D. Reardon, the principal investigator.
The hardcopy data sheets and video recordings will be kept for a period of 5 years after publication and then destroyed.

If you agree to participate in this project, you will be given a copy of this background information and consent form to keep for future reference.

Your participation in this research project is entirely voluntary and you may refuse to participate or withdraw from the study at any time without adverse consequence. If you have any further questions regarding this project or the nature of the protocol, at any time before, during or after your consenting to participate, please contact:

Prof. Francis D. Reardon
School of Human Kinetics
Faculty of Health Sciences
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Ottawa, Ontario
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Fax: (613) 562-5149

Prof. Glen P. Kenny
School of Human Kinetics
Faculty of Health Sciences
University of Ottawa
Ottawa, Ontario
K1N 6N5, Canada
Email: freardon@uottawa.ca
Phone: (613) 562-5800 x4282
Fax: (613) 562-5149

If you have any ethical concerns with regards to your participation this study, you may contact the Protocol Officer of the University of Ottawa.

Protocol Officer for Ethics in Research
University of Ottawa,
Tabaret Hall,
550 Cumberland, room 159
Ottawa, ON
K1N 6N5, Email: ethics@uottawa.ca
Phone: (613) 562-5841

CONSENT

I ______________________________, have read the information concerning this research project and have discussed all other questions or concerns that I have had about this study with Prof. Francis D. Reardon and/or Prof. Glen P. Kenny. My questions have been answered.

I acknowledge receipt of a copy of this background information and consent form.

Volunteering Subject: ________________________________ Date:____________

Signature of Researcher: ________________________________ Date:____________

INFORMATION ET CONSENTEMENT DU SUJET

Les mineurs exposés à la chaleur : Le stress thermique dans les mines profondes mécanisées du Canada.

Chercheur principal: Francis D. Reardon
Co-investigateur: Glen P. Kenny
J.W. Snellen Memorial Laboratory
University of Ottawa, School of Human Kinetic

INTRODUCTION

Depuis un an, les chercheurs de l'Université d'Ottawa ont travaillé de près avec l'Organisation de recherche de l'industrie canadienne minière (CAMIRO) et le consortium de recherche des mines profondes (DMRC) afin d'évaluer les effets de l'exposition des mineurs à la chaleur dans les mines profondes. L'objectif de cette recherche est de revoir les normes actuelles de sécurité au travail dans les mines profondes du Canada. Il y a un grand besoin de minimiser l'exposition des travailleurs à la chaleur, car il semble que la température ambiante dans l'environnement du travail augmente selon la profondeur de la mine. Cette question est la considération prépondérante dans la conception des systèmes de climatisation dans miniers.

Compte tenu des coûts croissants de la climatisation de l'air, les questions touchant les niveaux d'exposition à la chaleur des mineurs et de leur sécurité, devront éventuellement être mieux comprises dans l'exploitation des mines Canadiennes profondes. D'un point de vue économique, si ces questions demeurent sans réponse, d'importantes réserves de minerai resteront inaccessibles. Il est donc essentiel de chercher des moyens pour optimiser la sécurité des mineurs et ainsi, garantir la viabilité des mines profondes et de la collectivité. De plus, l'optimisation de l'utilisation de l'énergie nécessaire pour le climatisation de l'air engendreront au Canada, la réduction de l'émission des gaz à effet de serre.

Présentement, les standards thermiques de travail dans les mines profondes sont fondés sur la qualité de l'environnement tandis que l'effet de ces conditions environnementales sur les conditions physiologiques des ouvriers demeure essentiellement inexploré. De plus, plusieurs normes étrangères ne s'appliquent pas aux conditions retrouvées dans les mines canadiennes creusées en profondeur.

Un des objectifs de ce projet de recherche est d'étudier le rôle de l'intensité de travail (et ainsi la production de chaleur métabolique), sur les problèmes reliés à l'augmentation trop prolongée de la température corporelle. Ce type de problème est critique lorsqu'on travaille dans un environnement chaud, tel que les mines.

Ce projet de recherche se déroulera en deux phases consécutives. La première phase sera de caractériser quelques tâches typiques de mineurs pendant une journée de travail. L'objectif de la deuxième phase sera d'évaluer le coût énergétique de ces tâches pendant un quart de travail.

Ce projet ne s'effectuera pas dans des conditions de températures élevées mais plutôt sous des conditions normales de travail, puisqu'il s'agit ici d'évaluer l'intensité de travail sans imposer un environnement extrême.

Ces études sont surtout de nature exploratoire et conçues pour évaluer en détail et caractériser le travail des mineurs pendant leur période de travail. Au cours de la première phase 1) nous enregistrerons sur bande vidéo pendant 6 heures, les mouvements et les déplacements d'un mineur pendant une journée type. À partir de ces enregistrements, 2) nous quantifierons ces tâches en les analysant en fonction du temps et des mouvements effectués. Au cours de la deuxième phase, nous mesurerons les changements de taux métabolique et de température corporelle chez le sujet effectuant de ces tâches.

INFORMATION

À titre de sujet nous vous demanderons de participer aux deux séances expérimentales d'une durée de 6 heures: 1) pendant la première, nous enregistreront sur vidéo-cassette votre travail quotidien pendant 6 heures. 2) Dans un deuxième temps, nous vous demanderons de porter un masque respiratoire qui couvre votre bouche et votre nez. Les gaz seront dirigés vers un analyseur portatif. Le volume expiré, la concentration d'oxygène et de gaz carbonique seront mesurées (avec l'appareil Sensor-Medics, Quinton, Seattle, USA). Cet appareil sera porté dans une pochette sur votre dos, sous votre combinaison de travail. Vos gaz expirés seront échantillonnés pendant 30 minutes à quatre reprises pendant le quart de travail de 6 heures.

Pendant la deuxième session, vous porterez 1) selon votre choix une sonde thermique, soit oesophagienne, rectale, tympanique ou soit gastrique. 2) Vous aurez également 12 sondes thermiques sur la peau. Les températures oesophagienne seront enregistrées en utilisant une sonde pédiatrique oesophagienne (2 mm de diamètre), insérée à travers la narine à une profondeur où le bout est situé près du cœur. Les températures rectales seront enregistrées avec la même type de sonde insérée cette fois dans le rectum à une profondeur de 20 cm. En ce qui a trait à la sonde tympanique, vous devez l'introduire dans le canal de l'oreille afin que le bout de la sonde soit à 1mm du tympan (≅ 1.5cm). Cette sonde est composée d'un fil fin et flexible, emballée dans du coton. La température gastrique sera mesurée en utilisant une sonde 'pilule' (de la taille d'un comprimé d'Aspirine) qui transmet (par ondes radio) la température pendant son trajet à travers l'estomac et les intestins. Vous devez l'avaler au moins une heure avant l'évaluation. Cette sonde est éliminée par défécation 24 à 48 heures plus tard. Elles sont à usage unique donc, ne peuvent être réutilisées. Les signaux, tout comme ceux des sondes oesophagienne et tympanique, sont captés par un système portatif porté dans un sac à dos sous votre combinaison.

Votre température cutanée moyenne sera estimée à l'aide de sondes placées sur la peau. Ces sondes superficielles (Concept Engineering, Old Saybrook, CT) seront collées sur la peau avec du ruban hypoallergène à 12 sites : le front (1) ; la nuque (1) ; le dos (2) ; la poitrine (2) ; l'avant-bras (2) ; la cuisse (2) ; et, le mollet (2). Ces sondes seront branchées directement au système de récolte des données au cours d'un cycle de 6 heures de travail.

Les risques de malaise ou d'inconvénient liés à la participation à cette recherche sont pratiquement nuls pendant les sessions d'enregistrement vidéo. La deuxième phase nécessite l'utilisation de ruban adhésif pour sécuriser les sondes thermiques. Bien que ce ruban adhésif soit

hypoallergénique, il peut occasionner des irritations mineures. Les mesures de consommation d'oxygène ainsi que l'insertion d'une sonde thermique oesophagienne, rectale ou tympanique peuvent aussi occasionner des malaises tels que des irritations temporaires des muqueuses.
Vous n'obtiendrez aucuns avantages directs de votre participation à cette recherche. Cependant, les chercheurs pourront obtenir beaucoup d'information sur les besoins énergétiques de mineurs canadiens. De plus, les résultats de l'étude seront partagés avec les participants sur demande.

Votre anonymat sera conservé, autant que possible en enregistrant vos activités à une distance (8 à 10 mètres). De plus, votre nom n'aparaîtrera sur aucuns documents et un code numérique sera utilisé pour vous identifier. Seulement l'ensemble des données et non les résultats individuels seront publiés dans les rapports et autres publications.

Votre information personnelle ainsi que les données brutes (vidéo) et codées (feuilles de données etc.) seront uniquement accessible par les chercheurs et les techniciens. Toutes les données seront gardés soit dans une ordinateur (fichier éléctronique cadencé - accès exclusif) dans un laboratoire du chercheur principale au Pavillon Montpetit.

Les données brutes et codées seront conservées pendant une période de 5 ans.

Votre participation à cette recherche est volontaire et la priorité sera sur votre sécurité. Vous pouvez vous désister à n'importe quel moment pendant ou après l'étude et ceci sans préjudice. À titre de participant, vous recevrez une copie de ce formulaire d'information et de consentement.

Pour de plus amples renseignements n'hésitez pas à contacter les responsables:

Prof. Francis D. Reardon
School of Human Kinetics
Faculty of Health Sciences
University of Ottawa
Ottawa, Ontario
K1N 6N5, Canada
Email: freardon@uottawa.ca
Phone: (613) 562-5800 x4270
Fax: (613) 562-5149

Prof. Glen P. Kenny
School of Human Kinetics
Faculty of Health Sciences
University of Ottawa
Ottawa, Ontario
K1N 6N5, Canada
Email: gkenny@uottawa.ca
Phone: (613) 562-5800 x4282
Fax: (613) 562-5149

Si vous avez des questions se rapportant à la conduite éthique de cette recherche, vous pouvez vous adresser à la Responsable de l'éthique en recherche de l'Université d'Ottawa.

Responsable de l'éthique en recherché,
Université d'Ottawa
Pavillon Tabaret
550 rue Cumberland, pièce 159
Ottawa, ON
K1N 6N5, Canada
courriel:ethics@uottawa.ca
tél: (613) 562-5841

CONSENTEMENT

Étant donné que les responsables ont répondues à ma satisfaction, à toutes mes questions à propos de cette étude, je, ______________________________, après avoir lu l'information et après avoir discuté à ma satisfaction, accepte de participer au projet mené par les Profs. Francis D. Reardon et Glen P. Kenny.

Sujet: ____ Date:_______

____

Chercheur: ____ Date:_______

____

APPENDIX B

B.1 Certification of Institutional Human Research Ethics Committee

B.1: Certification of Institutional Human Research Ethics Committee

Université d'Ottawa · University of Ottawa

Cabinet du vice-recteur à la recherche | Office of the Vice-Rector, Research

HEALTH SCIENCES AND SCIENCE RESEARCH ETHICS BOARD

CERTIFICATE OF ETHICAL APPROVAL

This is to certify that the University of Ottawa Health Sciences and Science Research Ethics Board has examined the application for ethical approval for Phases 2.1 and 2.2 of the research project entitled **Heat Stress in Canadian, deep, mechanized mines: Personnel heat exposure issues (file H 10-04-04)** submitted by Drs. Frank Reardon and Glen P. Kenny, of the School of Human Kinetics, Faculty of Health Sciences. Board found that this research project met appropriate ethical standards as outlined in the Tri-Council Policy Statement and in the Procedures of the University of Ottawa Research Ethics Boards, and accordingly gave it a Category 1a (approval). This certification is valid for one year from the date indicated below.

Rita D'Alessandro
Protocol Officer for Ethics in Research
For Dr. Daniel Lagarec, Chair of the
Health Sciences and Science REB

November 10, 2004
Date

550, rue Cumberland, Ottawa (Ontario) K1N 6N5 Canada | 550 Cumberland Street, Ottawa, Ontario K1N 6N5 Canada

(613) 562-5270 · Téléc./Fax (613) 562-5271

Université d'Ottawa · University of Ottawa

Research Grants and Ethics Services

November 10, 2004

Dr. Frank Reardon
School of Human Kinetics
University of Ottawa
125 Université
Room 352
Ottawa, ON K1N 6N5

Dr. Glen P. Kenny
School of Human Kinetics
University of Ottawa
125 Université
Room 376
Ottawa, ON K1N 6N5

Object: **Heat Stress in Canadian, deep, mechanized mines: Personnel heat exposure issues (file H 10-04-04)**

Dear Researchers,

You will find enclosed the Health Sciences and Science REB ethical clearance for Phases 2.1 and 2.2 of the abovementioned study.

Please note that it is the responsibility of the Researchers to:

a) Inform the ethics office of any changes in the research project; and
c) Fill out an annual status report to be sent to the Protocol Officer for Ethics in Research. Such report can be found on the ethics web site at: http://www.uottawa.ca/services/research/rge/rebs/download/rapport_annuel_projets_anglais.doc

A copy of this approval will be sent to Research Services, if necessary.

If you have any questions, you may contact me at the number 562-5387.

Sincerely yours,

Rita D'Alessandro
Protocol Officer for Ethics in Research
For Dr. Daniel Lagarec, Chair of the Health Sciences and Science REB

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Ottawa (Ontario) K1N 6N5 Canada

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Téléc./Fax (613) 562-5338