

**Some physiological effects of deep underground mining and the relationship  
with Physical Work Capacity and Functional Work Capacity assessment  
outcomes**

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## PREFACE

For the aim of this project it was decided to use article format. For uniformity the whole mini-dissertation was written according to the guidelines of the chosen journal for potential publication. The chosen journal, the Scandinavian Journal of Work, Environment & Health, requires that references in the text to be based on the “Uniform Requirements for Manuscripts Submitted to Biomedical Journals”, numbered consecutively in the order in which they are first mentioned in the text. Identify references in text, tables, and legends by Arabic numerals in parentheses. Personal communication cannot be used as references but can be mentioned in the text in parentheses. If a publication has six or fewer authors, all authors are mentioned. When there are more than six authors, the first six authors are listed followed by “*et al.*”.

## AUTHOR'S CONTRIBUTION

The study was planned and executed by the following team:

Name	Contribution
Ms ET Durrheim	<ul style="list-style-type: none"><li>• Design and planning of study;</li><li>• Execution of all underground and surface monitoring;</li><li>• Literature searches, statistical analysis, interpretation of data.</li></ul>
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The following is a statement from the co-authors that confirms each individual's role in the study:

*I declare that I have approved the article featured in this document and that my role in this study, as indicated above, is representative of my actual contribution and that I hereby give my consent that it may be published as a part of Erna Theresia Durrheim's M.Sc. (Occupational Hygiene) mini-dissertation.*

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## SUMMARY

**TITLE:** The physiological effects of deep underground mining and the relationship with Physical Work Capacity and Functional Work Capacity assessment outcomes

**Motivation:** The South-African deep level gold mining industry has adapted in many ways, as the pursuit for gold has led deep into the earth core, where rock face temperatures measure around 60 °C. Ventilation adapted through engineering developments like refrigeration systems, creating cooler work environments to an extent. Despite these developments the risks of high ambient temperatures coupled with strenuous work and dehydration remains, leading to alternative methods of control that have to indicate whether employees have the necessary functional capacity to perform daily work tasks. **Objectives:** The objectives of this study were: to measure and compare the physiological effects of the tasks performed by workers in an underground mining environment; To measure the soundness of heart rate as a gauge of work stress in real-life work conditions, taking into account the stressors that influence it; to determine the efficacy of functional and physical work capacity assessments as a method of determining work readiness. **Methods:** A study group (n = 16) was chosen to represent the “most exposed” work population, all of whom have previously passed the functional work capacity and physical work capacity assessments. The assessments were repeated and the maximal oxygen uptake assessment was done. The participants were divided into two groups (n = 8) according to their work areas. Measurements were taken over a period of eight consecutive shifts. Each group was later divided into three groups as per the work they performed. Dehydration was determined through urine analysis and body weight changes. Heart rate was observed continuously through a heart rate monitor

and oral temperature was measured on an hourly basis. **Results:** The shift durations seen during this study were much longer than the customary 8-hour work day. The mean HR results of group I, which was suspected of having the most strenuous work, were very similar to the results for group II and III. This group did, however, have the highest % heart rate  $\geq 120$  beats per minute and mean cumulative heart beats, group III having the lowest. All of the groups were found to be mildly dehydrated at the end of their shifts, the urine specific gravity indicating that the participants were generally already considerably dehydrated at the onset of the shifts. Group I was the only group whose mean heart rate had a statistically significant correlation ( $r \geq 0.5$ ) with % weight loss. There was a statistically significant ( $p \leq 0.05$ ) correlation between heart rate and mean oral temperature for all of the groups. The participants that passed the functional work capacity and physical work capacity assessments were found to have performed comparatively better during the real-time shifts than those that failed. **Conclusions:** Although there were several employees that had a high mean maximum heart rate, none of the mean heart rates were higher than the self-pacing rate of 110 beats per minute. This ability of self-pacing was seen in the way the participants were able to manage energy expenditure by alternating between heavy and lighter tasks. A great concern is the fact that all of the participants had a % weight loss (0.9 – 2.8% weight loss) indicative of mild dehydration after the shifts, on top of morning urine specific gravity samples (1.020 – 1.025) showing signs of considerable dehydration. Several correlations were found between the functional work capacity and physical work capacity assessments and maximum temperature, maximum heart rate and maximal oxygen uptake, suggesting a significant relationship between the real life situation and the homogenous laboratory setting. Comparing the employees that passed the

functional work capacity and physical work capacity assessment to those that failed, a marked difference was seen in their respective performances. The groups that passed had a lower mean heart rate and maximum heart rate and higher maximal oxygen uptake. It may, therefore, be concluded that the functional work capacity and physical work capacity assessments provide a valid evaluation of an individual's work capacity and potential to cope with the varying demands of underground work.

**Keywords:** mining; physiological strain; physical work; heart rate; dehydration; self-pacing; functional capacity assessments

## OPSOMMING

**TITEL:** Die fisiologiese effekte van die diep ondergrondse myn omgewing en die verband met fisiese werkskapasiteit en funksionele werkskapasiteitsassesserings uitkomst

**Motivering:** Soos die Suid Afrikaanse goudmyn industrie se soeke na goud dieper en dieper in die aardkors in lei, moes dit noodsaaklike veranderinge ondergaan, om aan te pas by die nuwe dieptes, waar die rots wand temperature tot so hoog as 60 °C styg. Tegnieë vooruitgang het ventilasie sisteme aangepas om gebruik te maak van verkoelingsisteme, wat die werksplekke tot 'n sekere mate verkoel. Ongeag hierdie ontwikkeling, bly die risiko hoog, omdat die hoë omgewingstemperature gepaard gaan met harde werk en dehidrasie. Dit dien as die oorsprong van alternatiewe metodes van beheer, wat gebruik word as 'n aanduiding van die werknemers se funksionele vermoë om hul daaglikse take te verrig. **Doelstellings:**

Die doelwitte van hierdie studie was: om die fisiologiese effekte van take wat deur werkers in die ondergrondse mynbou bedryf uitgevoer word te meet en vergelyk; om hartsnelheid as aanduiding van werkstres in 'n myn omgewing, te toets in ag genome die stressors wat dit beïnvloed; om die doeltreffendheid van die funksionele en fisiese werkskapasiteitsassesserings as metode vir werksgereedheid te bepaal.

**Metodologie:** 'n Studie groep (n = 16), wat die "hoogs blootgestelde" werksbevolking verteenwoordig, is gekies. Al die deelnemende persone moes voorheen die funksionele en fisiese werkskapasiteitsassessering geslaag het. Hierdie assesserings is herhaal en die maksimale suurstof verbruik (VO<sub>2</sub> maks) is ook bepaal. Die studie groep is verdeel in twee afsonderlike groepe (n = 8) na aanleiding van afsonderlike werksplekke. Monitering is uitgevoer oor 'n tydperk van agt

opeenvolgende skofte. Die verdere groepsverdeling, wat die studiegroep in drie subkategorieë verdeel, was gegrond op die tipe werk wat deur elkeen verrig word. Dehidrasie is deur middel van liggaamsgewig-veranderinge en urienanalise bepaal. Deur gebruik te maak van 'n hartsnelheid-monitor, is die hartsnelheid voortdurend gemonitor, terwyl liggaamstemperatuur op 'n uurlikse basis geneem is. **Resultate:** Die gemiddelde skof duur soos gesien in hierdie studie, was baie langer as die gebruikelike 8 uur werksdag. Die gemiddelde hartsnelheid resultate van die drie groepe was baie soortgelyk, alhoewel groep I se persentasie hartsnelheid  $\geq 120$  slae per minuut, die hoogste was. Die groep het ook die hoogste gemiddelde kumulatiewe hartslae gehad, terwyl groep III die laagste was. Die persentasie gewigs verlies (0.9 – 2.8% gewigs verlies) het gewys dat al die groepe effens gedehidreer was aan die einde van hul skofte, terwyl urien soortlike gewig (SG) daarop gedui het dat al die werkers reeds aansienlik gedehidreer (1.020 – 1.025) was met die aanvang van die skofte. Groep I was die enigste groep waar hartsnelheid 'n statisties beduidende korrelasie ( $r \geq 0.5$ ) met % gewigsverlies getoon het. Hartsnelheid het 'n statistiese beduidende ( $p \leq 0.05$ ) korrelasie met liggaamstemperatuur gehad by al die groepe. Daar is gevind dat die persone wat die funksionele en fisiese werkskapasiteitassesserings geslaag het, beduidend beter gevaar het tydens die werklike ondergrondse skofte as diegene wat dit nie geslaag het nie. **Gevolgtrekking:** Hoewel verskeie werknemers 'n hoë gemiddelde maksimale hartsnelheid getoon het, was dit nie hoër as 110 slae per minuut wat geneem word as die boonste hartsnelheidsgrens vir werkers wat hulle eie werkstempo bepaal nie. Hierdie vermoë van die werkers was veral opsigtelik in die wyse waarop hulle hul energie verbruik bestuur het, deur swaar, moeilike take af te wissel met ligter take wat minder energie vereis. Dat die werkers reeds

betekenisvolle vlakke van dehidrasie by die aanvang van 'n skof gehad het en dan tot 'n verdere mate gedehidreer het, is 'n bron van kommer. Verskeie korrelasies is gevind tussen die funksionele en fisiese werkskapasiteitasesserings en die gemiddelde maksimale liggaamstemperatuur, hartsnelheid en  $VO_2$  maks. Daar bestaan dus 'n betekenisvolle verband tussen die werklike ondergrondse omgewing en die gestandaardiseerde laboratorium omgewing. 'n Merkbare verskil kan gesien word in die werksvertoning van werkers wat die funksionele en fisiese werkskapasiteitasesserings nie geslaag het nie, teenoor diegene wat het. Die groepe wat geslaag het, het 'n laer maksimale hartsnelheid en gemiddelde hartsnelheid gehad, met 'n hoër  $VO_2$  maks. Daar kan dus afgelei word dat die funksionele en fisiese werkskapasiteitasesserings 'n geldige evaluering verskaf van 'n individu se kapasiteit en potensiaal om die verskillende eise van die ondergrondse werksomgewing te hanteer.

**Sleutelwoorde:** mynbou; fisiologiese stress; fisieke werk; hart-snelheid; dehidrasie; self bepaling van werksintensiteit; funksionele werkskapasiteitasesserings

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## LIST OF SYMBOLS

%	Percentage
±	Plus/minus
≥	Equal to and more than
≤	Equal to and less than
<	Less than
°C	Degrees Celsius
cm	Centimetre
Cu	An endurance limitation with an effect on productivity
H <sup>+</sup>	Hydrogen ion
HR <sub>MAX</sub>	Maximal heart rate
kg	Kilograms
kg/m <sup>2</sup>	Kilograms per metre squared
km	Kilometre
L/hour	Litres per hour
L/min	Litres per minute
m	Metres
Max	Maximum
min	Minute
ml/kg/min	Millilitres per kilogram per minute
ml/min	Millilitres per minute
m <sup>2</sup>	Height in metres squared
M ± SD	Means ± standard deviation
ml	Millilitres
O <sub>2</sub>	Oxygen
p	Statistical significance
P <sub>CO2</sub>	Carbon dioxide partial pressure in blood

$P_{O_2}$	Oxygen partial pressure in blood
$r$	Correlation coefficient
$T_{MAX}$	Maximum body temperature
$VO_2$	Oxygen consumption
$VO_{2MAX}$	Maximal oxygen uptake
$\%VO_2$ peak	Percentage peak oxygen uptake
yr	Age in years

## LIST OF ABBREVIATIONS

AMA	American Medical Association
ATP	Adenosine triphosphate
BMI	Body mass index
bpm	Beats per minute
ECG	Electrocardiogram
FCE	Functional capacity evaluations
FWC	Functional work capacity assessment
HR	Heart rate
HRM	Heart rate monitor
i.e.	In example
PWC	Physical work capacity assessment
SG	Specific gravity (urine)
WHO	World Health Organisation

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# **Chapter 1**

## **GENERAL INTRODUCTION**

## **1.1. Introduction**

The South African gold mining industry is the largest producer of gold in the world, producing up to 60 percent of gold mined. In order to ensure production, it employs around 60 000 people, making it the second largest employer in South Africa (1).

The modern day process of prospecting is done by way of drilling or boring holes deep into the earth, in order to locate a gold reef. Once a viable reef is located, a mine is developed, by sinking a shaft to reach the areas of gold-bearing rock. Tunnels are driven at various levels from the shafts until the reef is found, where development will take place. Once development is completed, the reef will be mined by a process known as “stoping”, through drilling and blasting and other physically demanding tasks in a very taxing environment (1). Although refrigeration and ventilation have advanced greatly during the last few years, the high rock face temperatures at these depths still influences the ambient temperature, which is another environmental stressor to overcome (2, 3).

Although the mining industry has become more aware of ergonomics in theory, there are still numerous limitations constraining health and safety. This places even more emphasis on other control measures of which the most important will be ensuring that an employee’s functional capacity is equivalent to that of the physical demands of their work tasks and work environment (4, 5). These changes in industry led to the development of control measures such as the functional work capacity (FWC) and physical work capacity (PWC) assessments.

A functional work capacity (FWC) evaluation may be defined as a systematic, comprehensive and objective way to measure the maximum ability of an individual to

perform the physical tasks required of his work (6, 7). These evaluations are performed before a worker starts a new work or to evaluate the workers return-to-work ability (6). FWC test batteries simulate job tasks, while the individual's cardiovascular function is monitored.

Physical work capacity (PWC) assessments are part of or an extension of the FWC assessment, to determine the overall fitness of an individual. An indication of the workers full-shift endurance, over a period of 8 hours on a daily basis, should be provided by this test. The PWC test gives an indication of cardio-respiratory fitness, by means of a heart rate test (4). Heart rate was chosen as an indicative parameter of physiological effort because it is sensitive to the overall physiological response of the body to physical activity and stress (8). This test, usually conducted by means of a 10 minute step test at an external work rate between 30 – 40%, is used to assess cardio-respiratory fitness, and serves as an overall indication of an individual's ability to perform light, moderate or heavy manual work (4).

Although research has indicated that oxygen consumption is the best way to assess the precise amount of energy used during any physical task, the use of some of the direct measuring instruments (i.e. Douglas bag, Kofranyi-Michaelis respirometer, COSMED K2 and Oxylog) can be very cumbersome due to short battery life of the instrument and the orsonasal mask becoming uncomfortable if worn over an extensive period of time (9, 10).

Since there is a linear relationship between heart rate and oxygen uptake under controlled conditions, heart rate (HR) may be used as an indirect assessment method of energy expenditure (9). Unfortunately this method is not always very

precise as there are many external variables like high ambient temperatures, humidity and dehydration that influence heart rate response (11 – 13).

## **1.2. Objectives and hypothesis**

The underground gold mining industry is a very demanding work environment. This is not just because of the very strenuous nature of the work that is performed, but also because of the very inhabitable conditions in which the tasks have to be carried out. These conditions include factors such as high ambient temperatures, high humidity, restricted work environments and long traveling distances.

The objectives of this study are:

- To measure and compare the physiological effects of the tasks performed by workers in an underground mining environment.
- To evaluate the accuracy of HR (in comparison with PWC assessment) as an indicator of work stress in real-life work situations while taking into account the external stressors influencing it.
- To determine the efficacy of functional and physical work capacity assessment as a method of determining work readiness.

The following hypothesis will be investigated:

FWC and PWC assessments provide a valid evaluation of an individual's work capacity and potential to cope with the varying demands of underground work.

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# **Chapter 2**

## **LITERATURE REVIEW**

## **2.1 Introduction**

Many words can describe the gold mining environment, of which the term “hot” might be the most descriptive. As man has dug deeper into the core of the earth in search of this highly sought after precious metal, the environment becomes more and more inhospitable. Rock face temperatures increase as high as 60 °C (1) as one moves further and further into the crust of the earth, where work activities have only been made possible by engineering developments in ventilation and air conditioning systems that keep these areas cool and well-ventilated (2). This means that the work environment, as well as the work itself became more demanding, workers being exposed to high ambient temperatures, humidity, dangerous and restricted work sites, which also lead to changes taking place on other levels within the mining environment. Some of these changes included the manner in which employees were screened (i.e. pre-employment medicals) while supplementary assessments also became necessary to determine whether the employees were fit to carry out their specific work activities under these adverse conditions. Examples of the assessments that came about are the Functional Work Capacity (FWC) assessment and Physical Work Capacity (PWC) assessment (3) which will be discussed later. It is important to review the physiological consequences of carrying out work of such strenuous nature at temperatures such as those found within the deep level gold mining industry.

## **2.2 Physiological effects of exercise on the cardiovascular system**

As can be expected, there are various physiological changes that occur at the same time within the body when a person moves from rest to activity. The most likely change is that of cardiac output or blood flow, which can increase from 5 L/min (when at rest) to up to 35 L/min when working at a maximum capacity (4). This ability

of the circulatory system to provide an increased cardiac output in order to deliver sufficient oxygen and nutrients is just as vital as muscle strength. Cardiac output is explained as the amount of blood that pumps from the heart into the aorta within a minute and gives an indication of the volume of blood that flows through the circulation. Cardiac output is directly affected by body metabolism, exercise, age and the size of the body, as well as dehydration and psychological stressors (4). Cardiac output will increase because of the increase in heart rate and stroke volume. The increased heart rate is due to vagal withdrawal, which will cause an increase in sympathetic activity (5).

The intense increase in metabolism in active muscles during exercise, will act directly on muscle arterioles, causing them to relax allowing ample oxygen and nutrients through to sustain the muscle contraction. Peripheral resistance will decrease as a result, causing a decrease in arterial pressure, which in turn causes the nervous system to respond, triggering large vein constriction (6). Blood vessels throughout the body, and specifically those in the muscles and abdomen, are compressed by the contraction of muscles during exercise and even with the anticipation of exercise, which is mostly due to sympathetic activity, which cause vasodilation in the muscles (5, 6).

Both the vasoconstriction in blood vessels and increased cardiac output leads to an increased blood flow that is especially important, because of its function of facilitating the other major change in blood flow: blood flow distribution. During this change, more blood is directed towards the active muscles, heart and skin, while blood flow towards the brain, abdominal organs and kidneys, decrease. This is attributed to arteriolar vasodilation (leading to increased blood flow to skeletal and cardiac

muscles and the skin) and arteriolar vasoconstriction (due to nervous system activity, causing decreased blood flow in gastro-intestinal organs and kidneys). The increase in cardiac output is accommodated by an increased heart rate (HR), a small increase in stroke volume and the speed at which it is ejected, which in turn leads to considerable increase in pulse pressure (4, 5).

### **2.3 Physiological effect of exercise on the pulmonary system**

During vigorous exercise, there is as much as a 20-fold increase in oxygen usage and carbon dioxide formation. The exact mechanism of how ventilation is controlled during activity, especially where moderate exercise is concerned, is a complicated mechanism of which the major stimuli are ill-defined (6). Some researchers (4) consider the most probable stimuli to be an increased  $P_{CO_2}$ , a decreased  $P_{O_2}$  and an increased  $H^+$  concentration, although according to Hall (6), this is highly unlikely. They pointed out that research has indicated that there were no significant changes in the concentrations of these factors during exercise, while there is a large increase in the ventilation immediately after the onset of exercise. Blood chemical concentration does not have sufficient time to change, and one would believe that simultaneous neural signals to the respiratory centre, within the brain stem, and muscles (inducing muscle contraction) is a more likely explanation. Other factors, which increase rapidly at the onset of exercise decrease just as rapidly, at the culmination thereof and seem to play a minor part in stimulating ventilation. These changes occur so swiftly that it cannot be explained by changes in chemical composition or body temperature.

During maximal exercise, a normal young man will reach a pulmonary ventilation of 100 to 110 mL/min while his maximal breathing capacity is 150 to 170 mL/min,

indicating that the maximal breathing capacity is roughly 50 % greater than his actual pulmonary ventilation. This is a physical safeguard, ensuring that there is extra ventilation that can be utilized when the person is exposed to exercise under very hot conditions, at high altitudes and when there are abnormalities in the respiratory system. During exercise there is also an increased rate at which the oxygen diffuses through the respiratory membrane into the blood, which is known as the diffusing capacity. This increase is mainly due to the increased blood flow through the lungs, perfusing the respiratory capillaries at a maximum rate, which provides a far bigger surface through which oxygen can diffuse into pulmonary blood. The respiratory system is, therefore, not the limiting factor in ensuring the delivery of sufficient oxygen to the muscles, rather it being the capacity of the heart to pump enough blood (6).

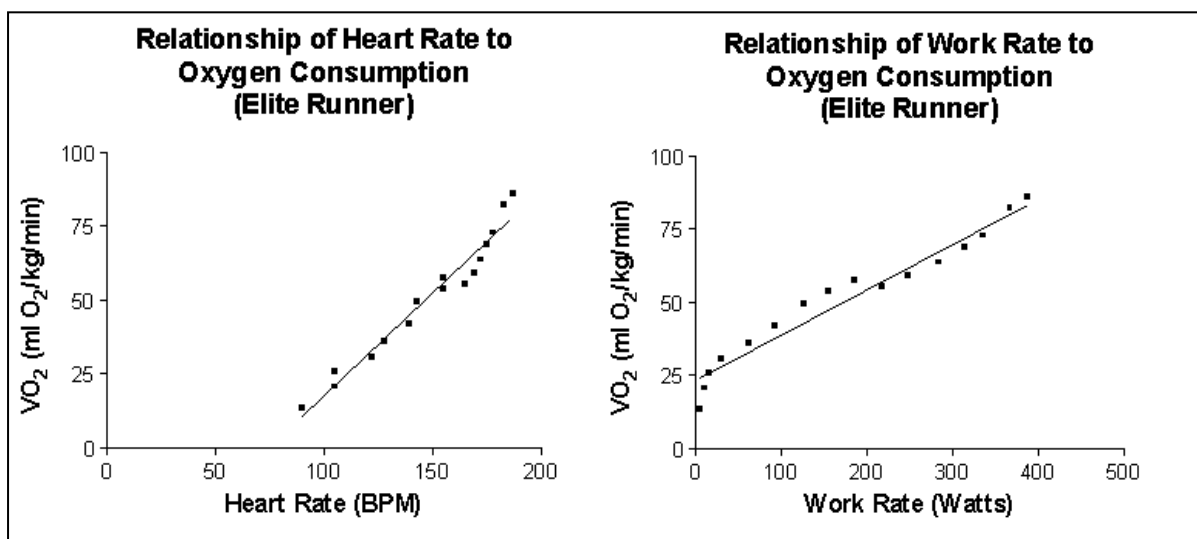
$VO_{2MAX}$ , or maximal oxygen ( $O_2$ ) uptake, is representative of the combined capacity of the pulmonary, cardiovascular and muscle systems' ability to absorb and transport  $O_2$  and is indicative of the rate at which oxygen is utilized under conditions of maximal aerobic metabolism (5, 6). While it is known that exercise can lead to the  $VO_{2MAX}$  increasing as much as 10 %, it seems that the frequency of exercise, whether it is two times or five times a week will have an equal effect (6).

#### **2.4 Heart rate and $VO_{2MAX}$**

It is believed that the measurement of peak (maximum) rate of oxygen consumption ( $VO_{2MAX}$ ) is the most accurate measure of directly determining work rate or energy expenditure and is expressed in either mL/min or mL/kg/min. These measurements quantify a person's capacity to utilize oxygen in the aerobic production of ATP (7 – 10). Research has shown that a high  $VO_{2MAX}$  will increase a person's physical work

capacity and, therefore, an increased ability to generate a larger amount of energy over an extended period of time (11).

Although a direct measurement is the most accurate way of measuring  $VO_{2MAX}$ , these assessments require trained personnel and make use of cumbersome, usually expensive equipment that may not have the ability to measure over long periods of time (7 – 10, 12, 13). This led to the development of various methods to predict  $VO_{2MAX}$  (13). The most commonly used indirect measure is that of continuous HR, an easy non-invasive method that relies mainly on the linear relationship that exists between HR and oxygen to estimate  $VO_{2MAX}$  (7, 10, 13).



**Figure 1.** The linear relationship between  $VO_2$  and HR, and  $VO_{2MAX}$  (14).

This method is based on the fact that when you have determined the relationship between HR and  $VO_2$ , HR can be used to determine  $VO_{2MAX}$ , which in turn reflects the intensity of work being performed (15).

Other factors to contemplate are the suggested difference in the relationship between  $VO_2$  and HR where exercise is compared with regards to the use of large

muscle mass compared to smaller muscle mass (as well as where static and dynamic exercise is concerned (16 – 19). Some researchers also found  $VO_{2MAX}$  to be dependent on training, where it will increase with training, while decreasing once the training is terminated.

## **2.5 Heart rate and heart rate monitors**

While the linear relationship between HR and energy expenditure ( $VO_2$ ) have long since been established (8), it has only been with the development of portable heart rate monitors (HRM) that it has become the most commonly used method of determining exercise intensity in the field. This has mainly come about because of the ease of use and the fact that a HRM can be used to measure whole shifts, even where they stretch longer than the normal 8 hours (9). Researchers such as Godsen, Caroll and Stone (20) compared HR data collected by way of wireless HRM to that of HR collected by an ECG. The findings, which were validated during rest and exercise at different intensities, indicated that a HRM was within 6 beats per minute (bpm) of the actual HR, 95 % of the time (20).

While HR may be one of the easiest parameters to measure, it is not the most precise method of determining energy expenditure because of the many external variables influencing it. Nielsen and Meyer (21) found that work rate estimated from HR measurements in the field, tended to be higher than when it was determined directly. This can be explained by factors such as work position, static or dynamic work components, age, core temperature and dehydration as well as a small day to day variation, which can have an influence on HR (15, 21, 22).

There have been various studies that have found an additional increase in HR when exercise is performed in a hot environment (23 – 26). This is explained by the fact that as environmental temperature rises, the extent to which the physiological heat loss mechanisms are able to function, begin to decrease. This can happen to the extent that core body temperature will begin to rise, in turn instigating an equivalent rise in HR (26 – 28). Studies have shown that this increase in HR can be up to 10 bpm and this may lead to an over-estimation of the intensity of exercise (24 – 26). This questions the use of HR as an accurate gauge of exercise intensity (29).

## **2.6 Body temperature regulation**

The human body is able to maintain core body temperature within a very narrow range ( $36.7 \pm 0.3$  °C), since even relatively small increases ( $\pm 3$  °C), can cause injury or lead to death (30 – 32). The changes in core body temperature are usually a result of increased activity or due to a change in the ambient temperature. If it does happen that core temperatures vary by more than 2 °C above or below 37 °C then it can be presumed that the thermal balance has been lost, which may lead to hyperthermia (33, 34). The World Health Organisation (35) considers a core temperature of 38 °C as the upper limit for workers.

The mechanisms ensuring a stable core temperature (maintaining a steady state), is therefore vital, since extensive increases lead to nerve malfunction and protein denaturation (4), whereas a temperature of 47 °C is considered to be the absolute limit for survival (35). These mechanisms work on the basis that heat production must always be equal to the heat loss and *vice versa*. When changes within metabolic rate and ambient temperature disrupt the steady state, the change in core body temperature is recognized by thermoreceptors, which in turn will launch a

reflex, changing several effector outputs that adapt to the increased heat production or heat loss causing body temperature to return to normal (4).

### **2.6.1 Mechanisms of heat loss or gain**

The gold mining industry is one of the hottest environments to work in and it is important to understand that evaporation of sweat from the skin, only begins to be effective when ambient temperatures rise above 34 °C, which is quite normal for the depths at which work is done (36). The efficiency of this mechanism is determined by variables such as low humidity and air movement, both factors that are not always easily come by underground, it being a very hot and humid environment.

Four different mechanisms play a role in the process of heat loss and gain namely: radiation, conduction, convection and evaporation. All four mechanisms support heat loss, evaporation the only mechanism not affecting heat gain as well (4, 15, 31).

When work or exercise is done in a hot environment, where ambient temperature approach skin temperature, non-evaporative (dry) heat dissipation is hampered. This means that heat loss by way of radiation, convection and conduction decreases to such an extent, that it can even lead to heat gain. This causes the body to become increasingly reliant on evaporative cooling (sweating) in order to bring about heat loss (32, 37).

Sweat is a watery solution, mainly made up of water and sodium chloride, which can be produced at a rate of up to 4 L/hour and is stimulated by sympathetic nerves through the secretion of acetylcholine (4). For sweat to have a cooling effect, it has

to evaporate. The rate at which sweat can evaporate is mainly determined by the water vapour concentration (relative humidity) of the surrounding air (4, 37).

Therefore, almost no evaporation will take place when a person is in a hot and humid environment, leading to discomfort even though the sweat glands will continue to produce sweat, which will either remain on the skin or drip off (4). Linear air velocity plays an important role in this, since it can help along the cooling effect of sweat, especially where activities involve movement (38).

### **2.6.2 Heat exposure and temperature adaptation (acclimatization)**

A person who has recently moved to a hot environment will not be able to participate in hard manual labour. This is because body temperature will rise, leading to a feeling of weakness and the danger of heat illness will be at its highest. This weakness will decrease after a number of days and body temperature will not increase as much as the first day. It is now said that this person has acclimatized to the heat (4, 37). This means that the continuous exposure to heat will stimulate the physiological adjustments that improve heat tolerance (38). When this exposure takes place within a natural environment, it is called acclimatization, while acclimation will take place during exposure to an artificial, controlled environment. Although this distinction can be made, the physiological result will be the same (39). It would take the human body approximately 7 days (36) to improve heat tolerance to such an extent that a person is acclimatized, with the major advantages completed 10 – 14 days after initial exposure (40).

A person's most important ability to adapt to hot environments is determined by changes in the rate at which sweating commences and its volume and composition

(27, 37, 41). To ensure that there is a greater change in this rate, it is suggested that a person is exposed to a humid heat environment, rather than a dry-heat environment (37).

One of the first changes to take place during acclimatization is the rise in skin blood flow. This is due to a lowering of the vasodilatory threshold, causing an increased blood flow to the skin, supporting dry heat loss to the environment (42).

The other way in which body temperature is maintained is through a change in the sweat response, since sweating is the most effective way of dissipating heat in a hot environment (4, 43). Sweating is initiated much sooner with greater volumes of sweat being produced (44). The composition of sweat is also different, the sodium concentration being considerably less than before acclimatization. This change in sodium concentration happens due to an increased aldosterone secretion, in order to minimize the loss of sodium through sweating. The sweat gland secretory cells will continue to produce a solution with a sodium concentration which is similar to that of plasma. As the solution flows toward the skin surface, sodium is reabsorbed back into the blood. This is stimulated by aldosterone in much the same manner that it stimulates the reabsorption of sodium in the renal tubes (4).

Rowell (27) found that prolonged exercise, while exposed to heat, cause cardiovascular function to improve, which in turn will lead to an increase in blood flow. This can be explained by the higher metabolic demand that needs to be met. The increased blood flow to the skin plays an important part for dissipating heat as well. Normal cardiac output becomes insufficient to meet the combined demands of both skin and muscle blood flow. Blood pressure decreases, which in turn causes a

decrease in blood flow to the skin, heat dissipation decreases as well and continued exercise will cause the core temperature to rise and heat illness may follow.

## **2.7 Heat stress and exercise**

During an aerobic capacity evaluation, which is done as part of the FWC assessment, the environment is always standardized, in order to exclude the effect of ambient temperature on the measurement of physiological effort (45). While this type of environment is easily accomplished in a laboratory setting, ambient temperatures tend to fluctuate underground. It is, therefore, very important to understand exactly how this very oppressive working environment will affect HR and its relationship to work rate.

### **2.7.1 Cardiovascular system and heat stress**

The extent to which the cardiovascular system is affected by exercise in heat, is dependent on the amount of heat stress experienced, the intensity and duration of the exercise, personal fitness, level of heat acclimatization and hydration status. As expected, the untrained, un-acclimated and dehydrated person will experience the greatest cardiovascular strain when performing prolonged exercise in a hot and humid environment (32). Rowel *et al.* (46) found that untrained persons exposed to graded exercise in heat, showed significant changes indicative of cardiovascular strain, such as a distinct increase in heart rate, almost reaching maximal values, a considerably lower stroke volume, central blood volume and cardiac output.

During exercise in heat, exercising muscles and the skin have to contend with one another, since cardiac output (pumping activity of the heart) is inadequate to compensate for both the increased muscle activity and elevated body temperature

(27). This is especially true during continued exposure to heat and exercise, where even acclimated persons will be unable to sustain a thermal balance (47). During this type of exposure, the blood pressure will begin to decline because of the increased blood volume in dilated cutaneous vessels. The body's first priority is to return blood pressure to normal, activating cutaneous vasoconstriction, inhibiting the flow of blood to the skin and, therefore, heat inhibiting dissipation as well. Core body temperature will, therefore, continue to rise as the exercise is continued (27).

### **2.7.2 Work rate and heat stress**

There have been many studies that reported heat stress to have no or little (might decrease slightly) effect on  $VO_{2MAX}$  (46, 48, 49). On the other hand HR has been shown to increase, thus causing the linear relationship between HR and  $VO_{2MAX}$  to dissociate (46).

Nybo *et al.* (50) found a pronounced (16 – 25 %) reduction in the  $VO_{2MAX}$ , where mild exercise was performed in heat. This leads to the conclusion that the dissociation between the HR –  $VO_{2MAX}$  is less than when it is assumed that  $VO_{2MAX}$  remain unchanged during exercise in heat.

Research by Arngrimsson *et al.* (51) confirmed that a gradual increase in ambient temperature (25 – 45 °C) will lead to an increase in mean HR and mean %  $VO_2$  peak utilized will increase uniformly. It should be mentioned that the authors suggest that this rise in HR is due to other factors rather than the change in ambient air temperature.

Where aerobic capacity is evaluated, a standardized environment is used. This means the thermal environment is controlled during the assessment in order to avoid the effect of temperature on measurement of physiological effort (44).

## **2.8 Dehydration and exercise**

As discussed earlier, the cardiovascular system is put under much strain during exercise in heat (32). While Rowel (27) concluded that there would be an increased blood flow to the skin in order to enhance evaporative heat loss, Nakasjima *et al.* (52) observed that during exercise, blood flow cannot be redistributed from the core to the skin at a level sufficient for heat loss, rather maintaining flow to the muscle. This is especially evident during dehydration, where both dry and evaporative heat loss is suppressed to a larger extent, even though body temperature increases (52).

### **2.8.1 The cardiovascular system and dehydration**

Dehydration, while reportedly having almost no effect on oxygen consumption, has been found to have a positive correlation with HR, where dehydration can lead to an increase in the HR of as much as 7.5 % (15). It has been indicated that HR can increase by an average of 10 – 18 bpm, where a person is only mildly dehydrated at 0.9 – 2.8 % of the overall body weight, while the resting HR of a person dehydrated at 4 % of their body weight can increase by as much as 5 %. This leads to the conclusion that HR will become more and more unreliable where it is used as a measure of energy expenditure (15, 28, 53).

### **2.8.2 Dehydration and other effects**

Dehydration cannot exclusively be linked to heart rate. The literature also indicates the effects it has on physical and cognitive performances. Dehydration of 1 – 2 %

bodyweight could cause a 22 – 50 % reduction in the work rate, while mental performance will start to decline at 2 %, after which the decrease is proportional to every percentage drop in body weight that is brought about by dehydration (36, 54, 55). Cian *et al.* (55) observed that dehydrated persons were able to perform tasks correctly but took longer to respond, due to lengthier decision making processes. They also found short-term memory to be affected. This highlights the importance of acclimatization.

### **2.8.3 Determining dehydration status**

It is, therefore, very important to understand dehydration and the methods used to determine a person's hydration status. Urine colour, while noted as a significant indication of hydration status, can be influenced by many factors unrelated to hydration (i.e. food, medications, and illness) and may, therefore, be of little use. Other methods which have been used in a field setting are specific gravity, creatinine concentration and hematocrit (56 – 60). These methods are all reliant on the provision of a urine sample before and after a shift, which can be very challenging, especially where the mining environment is concerned. Use of creatinine is especially problematic, as morning voids will yield higher urinary creatinine concentrations than urine samples that were collected at any other time during the day (59). This might be one of the reasons why the measurement of body mass changes is so widely supported. Body mass changes, while being referred to as the most practical and accurate method, does have drawbacks as well, where the use of only pre- and post-work changes in body weight may be a conservative approximation of the total loss of water in sweat. Harvey *et al.* (60) suggested one record the total fluid intake and excretion to increase accuracy.

Casa *et al.* (61) defined hydration levels with regards to urine specific gravity, also known as SG. A well hydrated person will have a SG lower than 1.010, while a minimally dehydrated SG is between 1.010 and 1.020. Significant dehydration will have a SG between 1.020 and 1.030 and anything higher than 1.030 is defined as extremely dehydrated.

## **2.9 Functional capacity evaluations**

### **2.9.1 History**

The most basic Functional Capacity Evaluations (FCE) has been around since the post-World War II era. The idea of systematic evaluations was introduced in 1944 by the American Medical Association (AMA) and focused on the maintenance and promotion of health among all workers (62). In the 1980's the need for a more specific functional evaluation arose. This came about as worker compensation systems began to call for more specific information with regards to the workers' functional capacities and limitations in order to speed up the return to work processes. These decisions, which used to rely on the prognoses and diagnosis of a physician, did not include the evaluation of worker capability or take into account job demands, which lead to the development of functional capacity tests that could be compared to the physical demands of jobs and occupations, while also incorporating diagnoses and prognoses (62, 63).

### **2.9.2 Functional capacity evaluations investigated**

A FWC evaluation may be defined as a systematic, comprehensive and objective way to measure the maximum physical and functional ability of an individual to perform the physical tasks required of his work (62, 64, 65). It is seen as an independent measurement system that matches an employee's physical ability with

vital and essential job demands, while identifying ways in which a task can be adapted to increase worker safety. To understand FCE's better, it is important to also grasp the meaning of the terms. *Functional* implies the execution of a calculated, significant or constructive task, which has a specific beginning and end, with a measureable result, while *capacity* specifies the maximum potential or ability of the person being examined. An *evaluation* is a systematic approach to the way performance is monitored and reported on and calls for a forensic examiner to study, evaluate and interpret the execution of a structured task or critical job (62).

The most notable functional capacity evaluations might be those that are performed before a person starts a new job and is used to determine the effectivity of rehabilitation. Other functions include the evaluation of workers return-to-work ability and formulating a baseline work hardening programme (3, 62, 64 – 67). Perceived FCE's should be mentioned as well. This type of FCE is very intricate as the occupational classification should encompass the full range of tasks that could be encountered frequently on a job. Each candidate should be able to perform each and every task at the maximum permissible level (62).

For these assessments to reflect the true nature of any work environment, is a task of great complexity, where inter-individual differences in energy costs for specific tasks as well as the dissimilarities in the day to day structure must be considered. The way in which energy costs are assessed need to be evaluated to ensure that not only tasks that have been labelled as "heavy", which might take up only a very small fraction of an 8-hour shift, are evaluated (68). Injuries, anthropometrics, age, lifestyle, and poor health are other factors that have an effect on a persons'

functional work ability and should also be taken into account where work placement is involved (3).

When PWC is assessed, one of the main factors that have to be taken into account is aerobic capacity, which is influenced by many factors. It is especially important where heavy aerobic work is concerned, as a person's capacity to perform such a task, is dependant on both maximum oxygen consumption (aerobic power, which declines over life) and the ability to maintain an adequately high level of oxygen transport (69). Shephard (69) pointed out that a decline in aerobic capacity with age is more likely to be greater than that of the decline in aerobic power. This is explained by the fact that as a person grows older, the ability to dispel metabolic heat, decreases. Muscle strength start to decline, with a resulting decrease in maximal oxygen uptake (68). Another physiological factor that should be considered is that of peak HR, which declines with an increase in age, from 195 bpm at age 25 to 160 -170 bpm at age 65. This is because of a decrease in ventricular compliance, catecholamine secretion and the numbers or sensitivity of myocardial adrenergic receptors as one age (70).

### **2.9.3 Importance of self-pacing**

In situations where a person is able to self-pace, energy expenditure is usually maintained at a level where there is little or no accumulation of lactate (69). Over a shift of 8-hours, the typical worker will be able to sustain about 40 % of aerobic power, with an unsubstantial accumulation of lactate. The ceiling value, however, is situational, and the value can decrease progressively from 50 – 35 % of aerobic power, where the specific task demands awkward body position, small muscle group use, intermittent peaks of more intensive physical activity, or where work is to be

done under adverse environmental conditions (68). Machine paced work on the contrary, may demand a standard rate of 4 – 5 times higher than the sustainable aerobic capacity. In theory this may lead to fatigue, heart attack or stroke, although few actual reports of this exist. This lack of evidence seems to underline the significance of understanding the effect relative capacity, rather than absolute capacity, plays in performance (71).

#### **2.9.4 Functional work capacity and physical work capacity assessments**

From the literature it can be seen that various different functional capacity evaluations have come to see the light of day. While each one is different, the main reason these assessments will still be used in the years to come is because of the information that it provides. Its major applications include assessments to determine job allocation and re-allocation, screening, the monitoring of progress during rehabilitation and for the rehabilitation process itself (3). The FWC assessment mentioned in this study, was developed for those purposes and will be discussed in more detail later on.

FWC test batteries should simulate various job tasks within the environment, while cardiovascular function is monitored. It is important that these tests provide evidence of whether an individual will be able to perform the actual work task, while coping with the physical environment. FWC is, therefore, assessed in terms of work output, time taken and physiological cost, by means of a productivity rating (3). PWC assessments are part of or an extension of the FWC assessment, to determine the overall fitness of an individual. An indication of the workers full-shift endurance, over a period of 8 hours on a daily basis, should also be provided by this test. The PWC test gives an indication of cardio-respiratory fitness, by means of a heart rate test (3).

It is believed that there might not be one single test that has the ability to cater for all clients, or for all assessment situations while still providing all the answers, which suggests that tests should rather be chosen to mirror the needs of the client, employee and work environment (72).

#### **2.9.4.1 Functional work capacity assessment investigated**

This study is focused on a FWC assessment that was designed specifically for the underground and opencast mining industry, taking into account the work environments and physical tasks that it entails. It consists of 19 test items that are categorized as functional work capacity elements to assess the ability to cope with the physical environment and functional work capacity elements that assess an individual's ability to cope with work tasks (3). Heart rate (HR), while only an indirect measure of energy expenditure, was chosen as the key parameter, because of its cost effectiveness, simplicity and sensitivity to the physiological response to physical activity (3, 7, 72).

The objective was to ensure that at least 95 % of the different elements that affect work capacity were considered and that each test item was realistic where the work environment and specific job tasks within the mining industry were concerned. Individual qualities such as strength and aerobic capacity, agility and dexterity, which play an important part in the performance of job tasks, had to be assessed as well. The test battery was structured in such a way that the FWC assessment was based on job tasks and work environments that could typically be associated with underground or opencast mining, accommodating both the functional requirements of the unskilled type jobs, as well as that of supervisors and more specialized

activities. The test items were designed to assess cardio-respiratory function, which indicates the ability of an individual to cope with the physical environment, functional mobility (of importance where an employee need to reach a far off workplace) and functional capacity, indicative of the ability to perform required manual work tasks (3).

All the tests included in the test battery (except where dexterity tests are concerned) were designed to have a specific physiological workload and time limit during which they have to be completed (3), where the work rate is equal to or better than a sedentary rate of 30 – 40 % of maximal oxygen consumption and a heart rate of about 110 bpm as explained by Astrand and Rodahl (8). This work rate was established on par with what would be the required work rate of an individual to carry out a full shift easily whilst self-pacing, taking into account age and sex, to avoid discrimination. To ensure that even disabled employees have a reasonable chance, no specific prescribed method has been identified for any of the test items, giving these employees the chance to adapt to the task where the only requirement is that the adaptation should not affect safety adversely.

Each individual will be evaluated in terms of the work output, time elapsed and physiological cost that is expressed in terms of a productivity rating. The interpretation of the productivity rating (Table1) is very important and should take into consideration both the individual himself and the functional requirements of the job task (3).

Specific test items were identified during a functional job analyses on all the physical tasks within the mining environment. This was followed up with the development of

productivity ratings (Table 1). Test items were matched with critical aspects of jobs and classified in terms of the physiological workload. Each category was classified in terms of ergonomic criterion and awarded with an exclusive colour, and can be seen in appendix A (3). It should be taken into account that an employee will not be automatically disqualified when rated category Cu. It is important to look at the overall productivity and take into account the specific job or task profile.

**Table 1.** The interpretation of productivity ratings for the FWC assessment (74).

<b>Category</b>	<b>Interpretation</b>
<b>A</b>	Eminently fit
<b>B</b>	Acceptable; no restrictions
<b>Cu</b>	Endurance limitation with an effect on productivity
<b>Cl</b>	Marked endurance limitation
<b>D</b>	Unacceptable; review and consider alternatives
<b>X</b>	Could not complete the test / test discontinued.

Tasks were rated per Table 2. High priority tasks (rated 3) can be described as tasks with high exposure, i.e. where the task take up more than 34 % of a normal 8-hour work shift, or where it can directly impact on the safety of the worker. Tasks rated as 2, or medium priority, have an exposure of less than 34 % of a normal work shift, where a rating of 1 (low priority) can be applied to any activity that has an exposure level of less than 34 % twice a week. The ratings of each task will then be used to determine the recommended score an employee needs to achieve in order to be able to perform these specific tasks (3).

During all tasks the employee is fully fitted with the correct prescribed protective equipment, not only as part of the safe work procedure, but also to take into account the effect that it has on work capacity and ability (3).

**Table 2.** The rating of job requirements as per the FWC assessment requirements (74).

Rating	Job requirement
3	<i>High level of priority:</i> Daily exposure of 34 – 66 % per work shift.
2	<i>Medium priority:</i> <ul style="list-style-type: none"> <li>- Daily exposure of &lt; 34 % of the work shift; or</li> <li>- Occasional exposure of 34 -66 % per work shift, not more than twice per work week.</li> </ul>
1	<i>Low priority:</i> <ul style="list-style-type: none"> <li>- &lt; 34 % of the work shift, not on a daily basis and not more than twice per work week.</li> </ul>
0	<i>No exposure</i>

#### 2.9.4.2 Physical work capacity assessment investigated

The PWC assessment is used to determine cardio-respiratory fitness, by means of measuring heart rate (3). This parameter is indicative of physiological effort and is very sensitive to the overall physiological response of the body to physical activity and stress (73). The PWC assessment is conducted by means of a step-test of 10 minutes, with an external work rate between 30 – 40 % of the maximal oxygen uptake, which serves as an overall indication of an individual’s ability to perform light, moderate or heavy manual work. To ensure that all employees were tested at the same work rate (54 Watt), the stepping heights are adjusted with regards to each participant’s body mass range. The results were then interpreted with regards to the information in Table 3, where a person who was classified as having a “very heavy” job intensity, must have a HR below that of 110 bpm in order to pass, while the HR

of a person classified as doing a job with a “heavy” intensity should be below 120 bpm etc. (3).

**Table 3.** Interpretation of the PWC assessment results as per job intensity (3).

<b>Job intensity</b>	<b>Range (bpm)</b>
<b>Very heavy</b>	40 – 110
<b>Heavy</b>	111 – 120
<b>Moderate</b>	120 – 135
<b>Light</b>	136 – 150
<b>Sedentary</b>	151 – 210

## 2.10 References

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# Chapter 3

**Some physiological effects of deep underground mining and the  
relationship with Physical Work Capacity and Functional Work  
Capacity assessment outcomes**

This article will be submitted to the *Scandinavian Journal of Work and Environmental & Health*.

## **INSTRUCTIONS FOR AUTHORS**

**General.** All papers submitted to this journal must conform to the current update of “Uniform Requirements for Manuscripts Submitted to Biomedical Journals” (<http://www.icmje.org>) also known as the Vancouver style. Articles submitted should report original research studies that are relevant to occupational and health in a way that is accessible to readers of the Journal.

**Authorship.** The corresponding author should be identified in the submission. Full postal addresses must be given for all co-authors. The preferred practice is that persons should only be named as authors if they have made significant identifiable intellectual contributions to the work, and other contributions may be recognised by acknowledgement at the end of the submission, in accordance with the guidance issued by the International Committee of Medical Journal Editors. A letter consenting to publication should be signed by all authors of a submission and sent to the Editorial Office.

**Conflict of interest.** The source of financial support for the work must be stated in the Acknowledgements, unless it is clear from the author’s affiliations. Other conflicts of interest must be declared to the Editor at the time of submission. These may include financial interest in products described, including stock or share ownership, and payment for consultancy or legal testimony using the material in the paper. These conflicts will not necessarily prevent publication, but the Editor may decide that the declaration should be included in the paper.

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**Brevity and supplementary material.** The necessary length of a paper depends on the subject, but any submission must be as brief as possible, consistent and clear. The number of words, excluding the abstract, references, tables and figures, must be stated as a message to the Editor at the time of submission. The average length of an article should be about 3000 or no more than 7 pages (about 21 typed pages, double-spaced and in 12-point font, tables and figures included). If necessary longer articles will be accepted with a page charge for all articles exceeding 7 printed pages. It is possible to include supplementary material, such as large data sets, in the on-line edition only, and authors are encouraged to take advantage of this. This material must be included in the submission, but not in the word count.

**Structure.** Papers should generally conform to the pattern: Introduction, Methods, Results, Discussion and Conclusions - consult a recent issue for style of headings. A paper must be prefaced by an abstract (no more than 250 words) of the argument and findings, which may be arranged under the headings: Objectives, Methods, Results, and Conclusions. Keywords (no more than 10) should be given after the abstract, in alphabetical order. Words appearing in the title do not have to be listed.

**Units and symbols.** SI units should be used, though their equivalent in other systems may be given as well.

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The list of references should correspond with the text and numbered consecutively in the order that they are first mentioned. Where there are more than six authors, the first six authors should be listed followed by “*et al.*”. Examples are given below. ISBNs should be given for books and other publications where appropriate. Personal Communications, if essential, should be cited in the text in the form (Professor S. Rappaport, University of California). References will not be checked editorially, and their accuracy is the responsibility of authors.

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# **Some physiological effects of deep underground mining and the relationship with Physical Work Capacity and Functional Work Capacity assessment outcomes**

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## **Abstract**

**Objectives** To measure and compare the physiological effects of tasks performed by workers in an underground mining environment; to measure the soundness of HR as a gauge of work stress in real-life work conditions, taking into account stressors that influence it; to determine the efficacy of functional and physical work capacity assessments as a method of determining work readiness.

**Methods** A study group representing the “most exposed” population was chosen having previously passed FWC and PWC assessments. Physiological strain was measured over a period of eight consecutive shifts.

**Results** Mean HR results across the sample group showed similarities, although group I had highest percentage HR  $\geq$  120 bpm and mean cumulative heart beats. Urine SG results indicated considerable dehydration at onset of shifts, additional weight loss seen during the shifts suggestion mild dehydration as well. Participants

that passed the FWC and PWC assessments were found to have performed comparatively better during real-time shifts than those that failed.

**Conclusions** Although several employees had high mean HR<sub>MAX</sub> results, mean HR did not cross the self-pacing rate of 110 bpm. The self-pacing ability is evident in the way participants managed energy expenditure, alternating heavy and lighter tasks. The study group had a % weight loss indicative of mild dehydration after the shifts, morning urine SG samples already indicating considerable dehydration. The correlations found between the FWC and PWC assessments and physiological indicators, suggest a significant relationship between real life situations and the homogenous laboratory setting.

**Key terms** mining; physiological strain; physical work; heart rate; dehydration; self-pacing; functional capacity assessments.

## **Introduction**

The underground gold mining industry can be looked upon as one of the harshest work environments, where many physically demanding tasks form part of the normal day-to-day routine. The often restricted environment calls for employees to walk long distances to reach their place of work, while environmental stressors, such as heat, are an added obstacle to overcome. At the time of the study, the South African gold mining industry had reached underground depths of up to 3.5 km with plans of still going deeper. At these depths, rock face temperatures reach up to 60 °C (1). Due to engineering developments in the recent years, ventilation and refrigeration systems are able to cool work sites down to a certain extent, but heat disorders still remain a risk where the high ambient temperatures are coupled with high humidity, strenuous

work and dehydration (1, 2). This emphasizes the necessity of control measures such as pre-employment screening that was developed by the mines to assess heat tolerance and employees' functional capacity to perform the necessary work tasks.

Heart rate (HR) is an easy, indirect method of continuously measuring physiological effort. This is because of its largely linear relationship with oxygen uptake (3 – 5) and its sensitivity to the overall physiological response of the body to physical activity and stress (6). Through the literature it is well known that HR can be affected by other physiological variables such as age, core body temperature and dehydration (4, 7, 8).

Various studies have found an additional increase in HR when exercise is performed in a hot environment (9 – 12). This increase may be as much as 10 beats per minute (bpm) and can lead to the over-estimation of the intensity of exercise (10 – 12). This trend is most likely explained by a corresponding increase in core body temperature, when a person is exposed to heat. The mechanisms for body temperature regulation (i.e. convection, conduction, evaporation, and radiation), are only effective to a certain extent, when exposed to heat (4, 13). In hot conditions when dry-air temperature approaches or exceeds skin temperature, heat loss by way of radiation, convection and conduction decrease so much that it can even lead to heat gain, causing the body to become increasingly reliant on sweating (evaporative cooling) to bring about heat loss (13, 14). The rate at which sweating starts, as well as the sweat composition and volume will change when one is continuously exposed to this type of environment. This is called heat acclimatization (13, 15). The efficiency of this mechanism is dependent on factors such as humidity and air movement in the

surrounding environment, where high humidity (such as that found in the underground gold mining industry) will hamper the effectiveness thereof, consequently impeding heat loss (12, 14 – 16).

The heat induced increase in sweat rate can lead to dehydration, which having almost no effect on oxygen consumption showed a significant positive correlation with HR. Dehydration also affects physical and cognitive performance (4, 5, 17 – 19). Research indicated that HR can increase by an average of 10 – 18 bpm, where a person was mildly dehydrated at 0.9 - 2.8 % of the overall body weight, while a loss in bodyweight of about 4 % can lead to resting HR to increase as much as 5 %. Consequently HR becomes a more and more unreliable measure of energy expenditure during dehydration (4, 16, 17).

The Functional Work Capacity (FWC) and Physical Work Capacity (PWC) assessment as described by Hofmann and Kielblock (20), was developed as a way of testing whether employees' functional capacity is equivalent to that of the physical demands of their work tasks in the underground and opencast mining environments.

The FWC assessment consists of 19 job based tasks that are typically found in the mining industry (20). All the tests were designed to have a specific physiological workload and time limit during which it has to be completed (20), where the work rate is equal to or better than a sedentary or self-pacing rate of about 110 bpm (3). Results for this assessment are expressed through a productivity rating as seen in Table 2 (p 51; 20).

PWC assessments determine cardio-respiratory fitness, by way of a 10-minute step test, with an external work rate between 30 – 40 % of the maximal oxygen uptake (110 bpm). It serves as an overall indication of an individual's ability to perform light, moderate or heavy manual work and is measured through HR (3, 6, 20).

## **Study population and methods**

### ***Study population***

All participants gave informed written consent (annexure B) for the study and the Ethics Committee of the North-West University approved the study. The ethical approval number is NWU-0074-08-A1.

This study consisted of 16 healthy male employees of an underground gold mine, ranging from 22 to 52 years of age. The participants were chosen to represent the “most exposed” work population – i.e. miners doing the most strenuous work within the stopes, in areas that was classified as “hot spots”. These participants have all previously passed heat stress, FWC and PWC assessments as part of the mine's medical screening. The criteria for their job categorization, “Very Heavy Work” (21), can be seen in Table 1.

**Table 1.** Criteria for job categorization for the whole assessment group (21) [PWC = Physical work capacity assessment; FWC = Functional work capacity assessment; MAX = Maximum; Cat B = Category B, as seen in Table 2].

		Minimum Requirements	Criteria
<b>Job Categorization</b>	<b>Very Heavy Work</b>	<b>PWC Test</b>	<b>Manual Material Handling:</b>
		≤110 bpm	Consists of 34 – 66 % of the work shift (daily exposure)
		<b>FWC Test</b>	<b>Work environment:</b>
		- <b>MAX load handling:</b> 30 kg	Manual material handling take place in restricted work environments (ceiling heights of 0.850m - 1.5m)
		- <b>Frequent lifting:</b> Cat B	<b>Heat exposure:</b> Daily exposure to high environmental heat loads for more than 34 % of the work shift
		- <b>Barring:</b> Cat B	<b>Production / Non Production related:</b> Work tasks are imposed by a process (directly linked to production)

### **Study design**

The 16 participants were made up of two teams divided equally: Team A (n = 8) and Team B (n = 8), situated within different areas within the mine. At the onset of the study, both groups of participants repeated the FWC and PWC assessments (22) on site at the mines medical centre. Anthropometric data was also obtained at this time.

Each group (A and B) was observed separately over a series of eight consecutive shifts, over a period of five weeks. Before and after every shift the participants were required to provide a urine sample, after which they were weighed and had their core body temperatures, through oral temperature measurements. During the shifts, the participants were monitored for heart rate, core temperatures. Each participant was also observed for the type of manual work done during a shift, as an indication of the strain of the physical activity.

## ***Occupations***

The participants (n = 16) were divided into three groups with regards to the work they performed during their shifts: (Group I) drilling (n = 6) – miners that spent most of their day with a rock drill, drilling holes into the rock face, (Group II) barring and support (n = 6) – miners who supported the person drilling and cleaning out the drill holes and/or miners who put up stope support (roof support) and moved the timber for pack building, (Group III) miscellaneous work (n = 4) – miners who were not constantly in the stope and did work within the shaft areas, such as shovelling rocks, laying cement, fixing support etc.

## ***Functional and physical work capacity assessment***

Both the assessments were conducted on site at the medical centre of the mine, as described by Hofmann and Kielblock (20). The FWC assessment test battery consists of various activities testing functional mobility (restricted mobility and climbing ladders) and load handling ability (frequent lifting, barring and pack building) with a specific physiological workload. Each participant had to complete the task within a realistic time frame with an equivalent physiological effort (heart rate) equal to a sedentary work rate of 110 bpm. Each employee was rated according to their performance as per Table 2. For analysis purposes each symbol was given a numeric value. The PWC assessment was used to evaluate cardio-respiratory function, which is done in the form of a 10-minute (min) step test, whilst measuring the heart rate response. In order to ensure that all employees were tested at the same work rate (54 Watt), the stepping heights are adjusted with regards to each participant's body mass range.

**Table 2.** The interpretation of productivity ratings for the FWC assessment and the assigned values for statistical analysis purposes (22).

Category	Assigned Numeric Value	Interpretation
A	1	Eminently fit
B	2	Acceptable; no restrictions
Cu	3	Endurance limitation with an effect on productivity
Cl	4	Marked endurance limitation
D	5	Unacceptable; review and consider alternatives
X	6	Could not complete the test / test discontinued.

### ***Anthropometry***

The participants were measured for height (m) and weight (kg) at the commencement of the project. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m<sup>2</sup>; Table 3).

### ***VO<sub>2</sub>MAX assessment***

VO<sub>2</sub>MAX measurements were done in Potchefstroom at the NWU PUK FNB High Performance Institute by a qualified sport scientist. These measurements were done in order to determine each subject's true maximal aerobic capacity. The test was initiated by walking on a treadmill at a low speed and zero grade. The speed of the treadmill was then increased at regular intervals (30 seconds). Each subject wore a face-piece with a two-way valve. The subject inhaled air from the room, while expired air was analyzed by sensors measuring the volume and concentration of oxygen. This is known as open-circuit spirometry. As the workload increases, oxygen consumption increase linearly, until at a certain point the increase in intensity did not result in a corresponding increase in oxygen consumption. At this point oxygen consumption flattens out, despite the increasing workload. This is an indication that

VO<sub>2</sub>MAX have been reached (23). The PWC assessment was repeated as well, while measuring oxygen consumption.

### ***Dehydration status***

Each subject was required to give a urine sample before and after every shift in order to determine whether hydration status changed during each shift. The urine samples were collected in special leak-tight collection tubes provided by the laboratory services. After urine collection, the tubes were placed in a transport tray and kept in a refrigerator. Before transport to the laboratory, the urine was analysed by way of Combur<sup>®</sup> 10 Urine test strips, for urine specific gravity (SG). The urine samples were then transported to a Pathology Laboratory within a special cooler box. The laboratory analysed the urine for SG levels. Due to complications arising during the transport of the urine samples to the laboratory, some of the samples could not be analysed. The dipstick results will, therefore, rather be used as an indication of dehydration.

Each subject was weighed before and after every shift. In order to determine nude body mass, the participants were only clothed in shorts. The scale used was a Safeway electronic bathroom scale, measuring to one decimal. The difference in weight (weight before shift – weight after shift) is indicative of hydration status.

### ***Core body temperature***

Core body temperature was determined by way of a digital oral thermometer. This method was chosen because of the ease of use, as measurements were to be taken on an hourly basis, while the subject was continuing with his normal underground

tasks. The thermometer was inserted into each subject's mouth and held under the tongue for approximately one and a half minutes, once it was determined whether any fluid was ingested within 20 minutes of the measurement. The subjects were advised to avoid drinking shifting the thermometer and to keep the mouth completely closed, breathing only through the nose. These measurements took place before and after every shift as well. Each subject was provided with a Microlife MT 1671 automatic self-test thermometer (with an accuracy of  $\pm 0.1$  °C), which was labelled as per his subject code. After every use, the thermometers were wiped down with a 70 % alcohol solution (disinfectant) and thoroughly cleaned on a daily basis with the same solution.

### ***Heart rate***

Heart rate was monitored at 5 second intervals, throughout every shift by way of a Polar<sup>®</sup> heart rate monitor (HRM; Polar<sup>®</sup> S-710 and Polar<sup>®</sup> RS-400 models) and the Polar WearLink<sup>®</sup> transmitter band (placed around the chest). A monitor and transmitter were placed onto a subject after weight measurement each morning before going underground. The monitor was checked throughout the working day on an hourly basis. The transmitter and heart rate monitor was stopped and removed after each shift before being weighed. All of the transmitter straps were washed on a daily basis. The data acquired during each shift, were downloaded to a computer, daily.

### ***Statistical analysis***

STATISTICA<sup>®</sup> Software v10.0 (24) and SAS/STAT<sup>®</sup> v9.2 (25) was used for database management and statistical analysis. Basic descriptive statistics (24) were used to determine the arithmetic mean values and standard deviations, making use of

correlation matrices and multiple linear regressions to determine correlations and the statistical significance between groups and parameters. The statistical significant differences were determined through breakdown and one-way ANOVA analysis, as well as dependant t-tests. A value of  $r \geq 0.5$  and  $\leq 0.8$  is indicative of a moderate to strong correlation with a large effect (26, 27). A p-value of  $\leq 0.05$  indicates a statistically significant difference. Data was illustrated through Microsoft Excel 2010, Polar ProTrainer 5™ (28) and STATISTICA® (24).

## Results

**Table 3.** Means and standard deviations ( $M \pm SD$ ) for the total cross-sectional sample and contrasted by work categories. [BMI = Body mass index.]

Variable	Work Categories			
	Mean total sample (N=16)	Group I (Drilling) (N=6)	Group II (Barring and Support) (N=6)	Group III (Miscellaneous Work) (N=4)
Age (yr)	35.9 ± 9.3	40.3 ± 5.5	33.5 ± 10.2	33 ± 12.2
Height (cm)	171.1 ± 5.2	172 ± 5.8	169.8 ± 4.8	171.8 ± 5.8
Weight (kg)	68.0 ± 9.7	71.6 ± 11.1	66.3 ± 10.7	65.3 ± 5.7
BMI	23.2 ± 3.1	24.1 ± 3	23 ± 3.7	22.2 ± 2.8

It is evident (Table 3) that the mean ages of the three groups varied from 33.5 – 40.3 years; where group I had the highest age. Group I showed the highest mean body weight ( $71.6 \pm 11.1$  kg) with the lowest ( $65.3 \pm 5.7$  kg) found in Group III. The mean BMI for all the participants studied was within what is the normal range (18.5 - 24.9  $\text{kg/m}^2$ ) as designated by the World Health Organisation Expert Committee (29).

From Table 4 it can be seen that the mean shift duration for all of the participants ( $n = 16$ ) was  $610.7 \pm 48.1$  minutes (about 10.16 hours). Group I had the highest mean shift duration,  $640.6 \pm 34.9$  minutes (about 10.68 hours), group II in the middle with

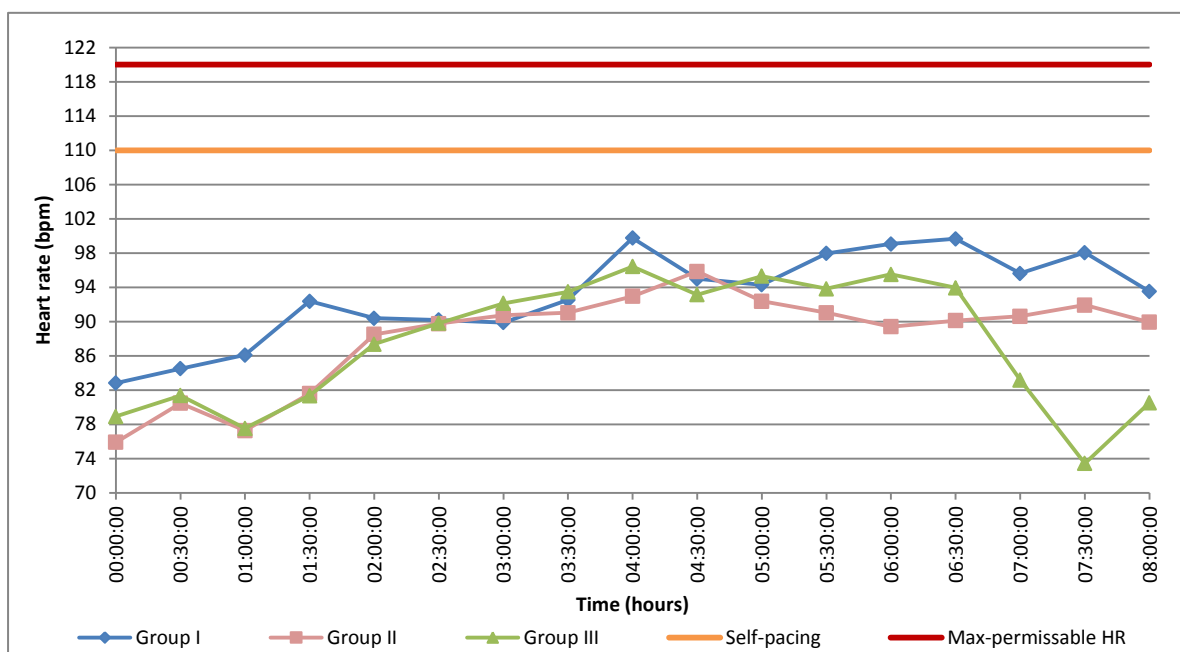
612.5 ± 50.6 minutes (about 10.2 hours) and group III the lowest mean shift duration of 563.0 ± 21.0 (about 9.38 hours). This was also reflected within the strong statistical significant difference that was found between group I and III ( $p \leq 0.05$ ). The longest overall shift (982.3 minutes, approximately 16 hours) took place during shift 2, with a group I participant. This was due to mechanical complications with the cage lift.

**Table 4.** Means and standard deviations ( $M \pm SD$ ) for the total cross sectional sample (over 8 shifts) contrasted by work categories. [ $HR_{MAX}$  = maximum heart rate;  $VO_{2MAX}$  = maximal oxygen consumption; Urine SG = Urine specific gravity.]

Variable	Work Categories			
	Mean total sample (N=16)	Group I (N=6)	Group II (N=6)	Group III (N=4)
Shift duration (min)	610.7 ± 48.1	640.6 ± 34.9	612.5 ± 50.6	563.0 ± 21.0
Mean HR (bpm)	88.0 ± 9.9	90.3 ± 10.9	87.0 ± 9.1	86.0 ± 11.5
Mean $HR_{MAX}$ (bpm)	150.6 ± 14.7	151.5 ± 14.4	151.5 ± 16.0	147.8 ± 17.0
Mean oral temperature (°C)	36.7 ± 0.5	36.8 ± 0.5	36.8 ± 0.6	36.7 ± 0.4
Mean $VO_{2MAX}$ (mL/kg/min)	33.5 ± 5.7	28.4 ± 2.2	34.6 ± 3.7	37.4 ± 6.9
% of actual shift ≥ 120 bpm	8.8 ± 7.8	11.1 ± 11.7	8.1 ± 4.7	6.4 ± 4.5
Total cumulative heart beats per actual shift	53407.9 ± 9156.1	58312.4 ± 8067.7	50559.1 ± 8872.0	45296.8 ± 8218.1
Total cumulative heart beats per 8-hour shift	41741.6 ± 5255.2	42469.5 ± 5589.6	42943.5 ± 4222.8	38846.9 ± 6416.6
Total weight loss during shift (kg)	0.9 ± 0.8	1.28 ± 0.8	0.8 ± 0.4	0.5 ± 0.3
% weight loss during shift	1.2 ± 1.4	1.87 ± 1.2	1.08 ± 0.7	0.77 ± 0.6
Urine SG Dipstick – Before	1.025 ± 0.003	1.025 ± 0.002	1.024 ± 0.003	1.026 ± 0.002
Urine SG Dipstick – After	1.026 ± 0.003	1.025 ± 0.002	1.029 ± 0.003	1.029 ± 0.002

The mean HR across the sample group was found to be 88.0 ± 9.9 bpm, with the highest mean HR seen in Group I (90.3 ± 10.9 bpm). In order to compare the results of each shift over a typical eight-hour day, the middle eight hours of each shift was calculated. This was done by subtracting eight hours from the total shift duration, dividing the answer by two, and subtracting this amount of time at the start and at the

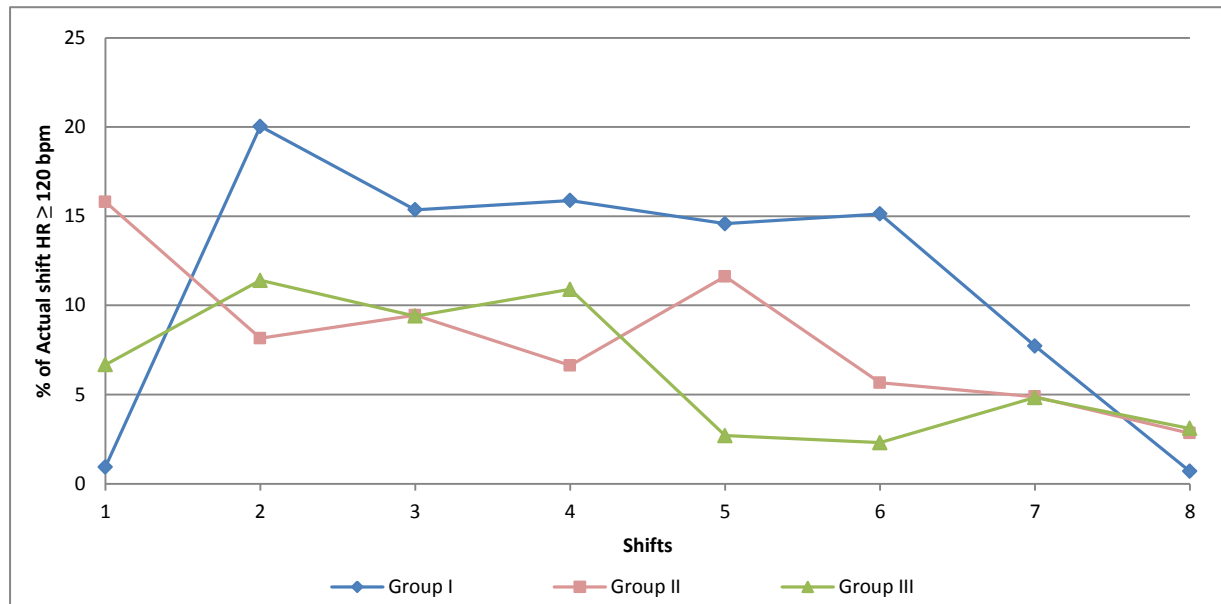
end of each shift. This method was used to calculate all values where an eight-hour shift is mentioned. Figure 1 shows the mean HR for all the groups across an eight-hour work-day. In this figure, it can be seen that all of the groups' mean HRs rose steadily over the day, with group I peaking at midday. It should be noted that groups II and III had a very similar increase in mean HR over the first three hours, with group III peaking first. Both groups I and II flattened out more towards the last three hours, while group III had a sharp decline, up until the last half-hour.



**Figure 1.** The mean half hourly HR across an eight-hour work-day for groups I, II and III.

All of the groups (Figure 1) had a maximum HR higher than the prescribed self-pacing HR of 110 bpm (3), which represents the work level that the normal healthy individual can easily carry out for a full shift. A single participant had a measured HR below that of 110 bpm, and this was only during one shift. The highest measured individual HR recorded was 195 bpm, considerably higher than the mean maximum HR.

120 bpm is the highest acceptable HR (maximum proposed HR) for work that is classified as heavy (22). On average, group I had the highest % HR  $\geq$  120 bpm over all the actual shifts ( $11.1 \pm 11.7$ ) and group III the lowest ( $6.4 \pm 4.5$ ). The % HR  $\geq$  120 bpm, as distributed over the measuring period ( $n = 8$ ), can be seen in Figure 2. There was no statistical significant difference between the three groups (Table 5).



**Figure 2.** A comparison of the actual percentage (%) HR  $\geq$  120 bpm during an actual shift for groups I, II and III over the eight shifts ( $n = 8$ ).

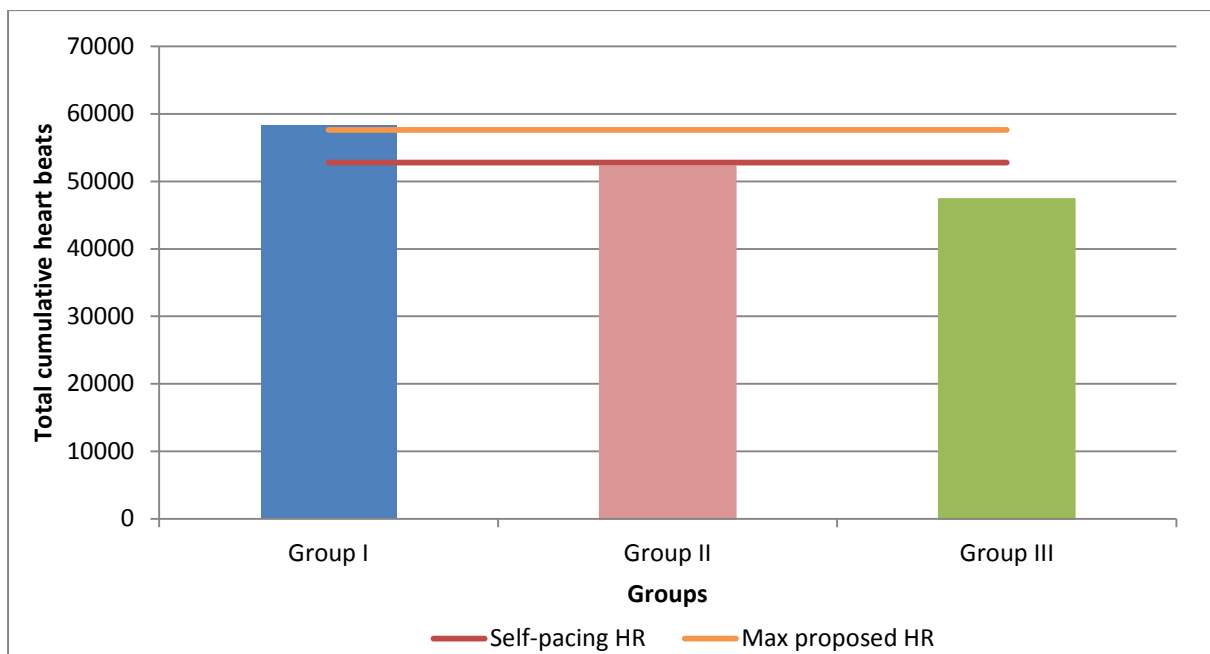
**Table 5.** The statistical significant differences between the different groups (I, II and III) with regards to the actual % HR higher than 120 bpm over eight shifts ( $n = 8$ ). [ $p =$  statistical significance.]

	Group I	Group II	Group III
	<b>p</b>	<b>p</b>	<b>p</b>
Group I	---	0.47	0.18
Group II	0.47	---	0.79
Group III	0.18	0.79	---

<sup>b</sup>  $p \leq 0.05$  – statistical significance

The mean total cumulative heart beats for each group over an actual shift, is illustrated in Figure 3. It was proposed that the actual shift time (which varies

between subject, shift and group) is equal to a 100 %. The cumulative mean sum of heart beats were then calculated per 100 % of a shift, for each group. Group I is the only group whose cumulative HR surpassed the self-pacing cumulative total heart beats (8 hours x 60 min x 110 bpm), as well as the maximum proposed cumulative total heart beats (8 hours x 60 min x 120 bpm). This is also evident from Table 4, which illustrates the mean total cumulative heart beats over an actual shift for all three groups. The only statistical significant difference ( $p \leq 0.05$ ) was found between group I and III (Table 5).



**Figure 3.** The mean cumulative total heart beats across an actual shift for groups I, II and III.

**Table 6.** The statistical significant differences between the different groups (I, II and III) with regards to the total shift duration over eight shifts ( $n = 8$ ). [ $p$  = statistical significance.]

	Group I	Group II	Group III
	<b>P</b>	<b>p</b>	<b>p</b>
Group I	---	0.38	0.0064 <sup>b</sup>
Group II	0.38	---	0.22
Group III	0.0064 <sup>b</sup>	0.11	---

<sup>b</sup>  $p \leq 0.05$  – statistical significance

The mean percentage weight loss for the whole sample group was  $1.2 \pm 1.4$  % with group I having the highest percentage weight loss at  $1.87 \pm 1.2$  % and the lowest group III ( $0.77 \pm 0.6$  %). A statistical significant difference ( $p \leq 0.05$ ) was found between group I and group III. There was no statistical significant difference ( $p \leq 0.05$ ) between the two methods of urine analysis (dipstick or laboratory analysis), or between the three groups. Both the dipstick (Table 4) and laboratory analysis of the urine SG indicated that all of the groups were considerably dehydrated (1.020 – 1.025), before going underground (30, 31). While some employees' dehydration levels continued to deteriorate during the shift (group II and III), the hydration levels of other employees actually increased over the duration of the shift. This may be due to these employees drinking more water during the shift.

Correlation coefficients were calculated to determine the relationship between mean HR and mean weight loss; mean HR and mean body temperature; and the mean  $HR_{MAX}$  and  $VO_{2MAX}$  for each group respectively. The results are represented in Table 7. The r-value is an indication of the strength of the correlation ( $r \geq 0.5$ ) where a negative correlation indicates a relationship between a variable that increases as the other decreases, while the p-value indicates whether the difference was statistically significant ( $p \leq 0.05$ ). Group I was the only group where a statistically significant ( $p \leq 0.05$ ) positive correlation ( $r = 0.92$ ) was found between mean HR and the percentage weight loss. All of the groups had statistically significant positive correlations between mean HR and mean body temperature (Table 7), an effect that is well supported in the literature (4, 12, 13). Group III was the only group where a correlation ( $r = - 0.95$ ) was seen between the mean  $HR_{MAX}$  and the  $VO_{2MAX}$ , which was also statistically significant ( $p \leq 0.05$ ). This trend corresponds with the linear

relationship, where a decrease in VO<sub>2</sub>MAX shows a corresponding decrease in maximum HR as well (3, 5).

**Table 7.** The correlation coefficients between some physiological parameters for each of the groups. [r = correlation coefficient; p = statistical significance; HR<sub>MAX</sub> = maximum heart rate (bpm); VO<sub>2</sub>MAX = maximal oxygen consumption (mL/kg/min).]

	Group I		Group II		Group III	
	r	p	r	p	r	p
<b>Mean HR and % weight loss</b>	0.92 <sup>a</sup>	0.001 <sup>b</sup>	0.36	0.38	0.22	0.61
<b>Mean HR and mean oral temperature</b>	0.74 <sup>a</sup>	0.0006 <sup>b</sup>	0.81 <sup>a</sup>	0.00009 <sup>b</sup>	0.69 <sup>a</sup>	0.002 <sup>b</sup>
<b>Mean HR<sub>MAX</sub> and VO<sub>2</sub>MAX</b>	-0.05	0.95	0.21	0.72	-0.95 <sup>a</sup>	0.04 <sup>b</sup>

<sup>a</sup> r ≥ 0.5 – strong correlation

<sup>b</sup> p ≤ 0.05 – statistical significance

The mean results for the different groups' FWC and PWC assessments can be seen in Table 8. The PWC assessment was based on HR, while FWC outcomes were assigned a symbol. Each of these symbols was given a numeric value in order to enable comparing it to other markers. Most of the participants met with the criteria (Table 1) for work with a job categorization of: "Very Heavy Work" (21).

**Table 8.** Average results per group for FWC and PWC assessments, performed at onset of study.

	Climbing Ladders	Frequent Lifting	Pack Building	Restricted Mobility	Barring	Total FWC	PWC (bpm)
<b>Group I</b>	2 (B)	1 (A)	2 (B)	1 (A)	2 (B) <sup>c</sup>	8	85
<b>Group II</b>	2 (B)	2 (B)	2 (B)	1 (A)	2 (B) <sup>d</sup>	9	100
<b>Group III</b>	2 (B)	2 (B)	2 (B)	2 (B)	2 (B) <sup>c</sup>	10	100 <sup>e</sup>

<sup>c</sup> One employee within this group was found to have an endurance limitation that could affect productivity in a compulsory activity.

<sup>d</sup> More than one employee within this group found to have an endurance limitation that could affect productivity in a compulsory activity.

<sup>e</sup> One employee within this group did not meet the standard of HR ≤ 110 bpm.

In the barring discipline (FWC assessment), five employees were unable to meet the requirements of a category B productivity rating, all of them scoring a Cu (endurance limitation with an effect on productivity), one employee respectively within group I and III, and three in group II. Only one employee did not meet the required 110 bpm upper limit for the PWC assessment (3, 6, 20).

Table 9 reflects these employees' mean performance over the eight shifts, grouped as employees who passed and failed the FWC assessment, across the complete sample group. In contrary, the PWC assessment is grouped by the employees who passed and failed the PWC assessment across the specific work category group in which the unsuccessful employee (Group III) fell. This is reflected in Table 10.

**Table 9.** Means and standard deviations ( $M \pm SD$ ) for the total cross sectional sample (over 8 shifts) categorized by a passed or failed FWC assessment. [ $HR_{MAX}$  = maximum heart rate;  $VO_{2MAX}$  = maximal oxygen consumption.]

Variable	Mean FWC assessment sample groups	
	Failed (n = 5)	Passed (n = 11)
Shift duration (min)	600.5 ± 56.7	609.2 ± 40.6
Mean HR (bpm)	95.0 ± 7.3	84.5 ± 9.3
Mean $HR_{MAX}$ (bpm)	159.8 ± 4.9	146.6 ± 16.3
Mean oral temperature (°C)	36.8 ± 0.2	36.5 ± 0.2
Mean $VO_{2MAX}$ (mL/kg/min)	32.4 ± 5.3	34.0 ± 6.1
% of actual shift ≥ 120 bpm	14.3 ± 10.1	6.1 ± 5.3
Total cumulative heart beats per actual shift	56748.2 ± 9930.3	50894.1 ± 7819.3
Total cumulative heart beats per 8-hour shift	45053.3 ± 3891.5	40119.1 ± 5203.8
Total weight loss during shift (kg)	0.5 ± 0.9	1.1 ± 0.7
% weight loss during shift	0.5 ± 1.7	1.5 ± 0.9

Looking first at the FWC assessment, it is seen that the failed group has a higher mean HR and mean  $HR_{MAX}$ , 95.0 bpm compared to 84.5 bpm and 159.8 bpm

compared to 146.6 bpm than the group that passed, respectively. Mean body temperature varied by 0.3 °C between the passed/failed groups, with the failed group having the higher mean oral temperature ( $36.8 \pm 0.2$ ). The failed group had a higher % HR  $\geq$  120 bpm (14.3 %) than the group that passed (6.1 %) the FWC (22). This trend continued when comparing the total cumulative heart beats per shift and over an 8-hour shift, where the group that passed had lower total heart beats than that of the group that failed. Neither group surpassed the maximum proposed cumulative total heart beats. The group that failed had a lower total and percentage weight loss than the group which passed.

**Table 10.** Means and standard deviations ( $M \pm SD$ ) for group III (over 8 shifts) contrasted by the passed and failed PWC assessment results. [ $HR_{MAX}$  = maximum heart rate;  $VO_{2MAX}$  = maximal oxygen consumption.]

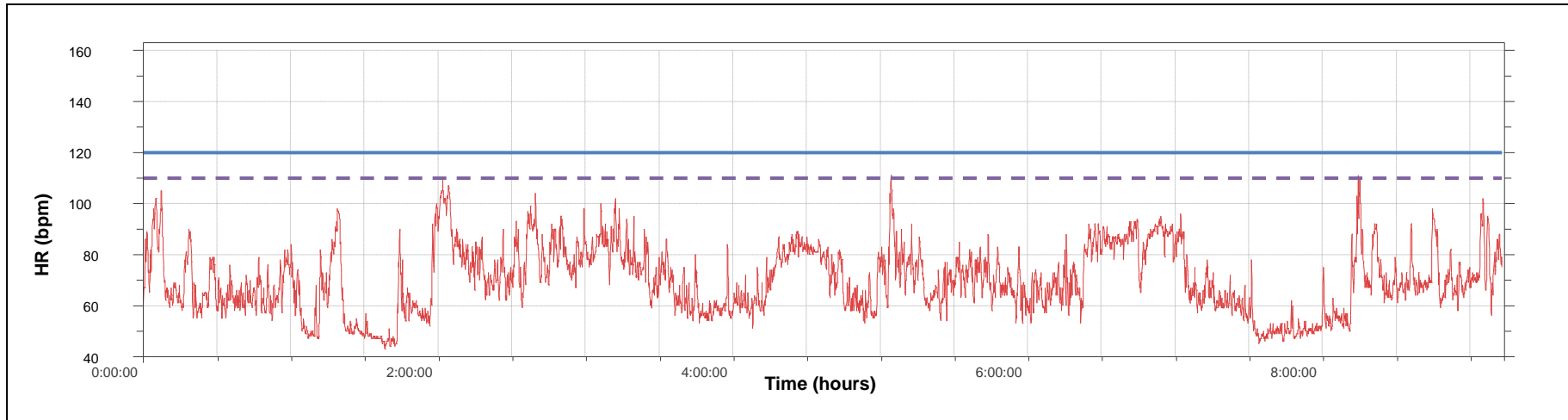
Variable	Mean PWC assessment sample group – Group III	
	Failed (n = 1)	Passed (n = 3)
Shift duration (min)	579.8 $\pm$ 39.0	557.4 $\pm$ 21.8
Mean HR (bpm)	89.5 $\pm$ 5.7	84.8 $\pm$ 13.8
Mean $HR_{MAX}$ (bpm)	156.4 $\pm$ 13.7	144.9 $\pm$ 19.6
Mean oral temperature (°C)	36.6 $\pm$ 0.6	36.7 $\pm$ 0.2
Mean $VO_{2MAX}$ (mL/kg/min)	31.2 $\pm$ 0.9	39.4 $\pm$ 6.9
% of actual shift $\geq$ 120 bpm	7.4 $\pm$ 6.1	6.1 $\pm$ 5.4
Total cumulative heart beats per actual shift	50767.8 $\pm$ 3455.1	43473.1 $\pm$ 9019.4
Total cumulative heart beats per 8-hour shift	42201.8 $\pm$ 4030.2	37728.6 $\pm$ 7365.9
Total weight loss during shift (kg)	0.4 $\pm$ 0.6	0.6 $\pm$ 0.1
% weight loss during shift	0.3 $\pm$ 1.8	0.9 $\pm$ 0.2

From Table 10 it can be seen that only one employee, from group III, was unable to meet the required 110 bpm upper limit for the PWC assessment (3, 6, 20). This employees' performance is compared to that of the other participants in his work

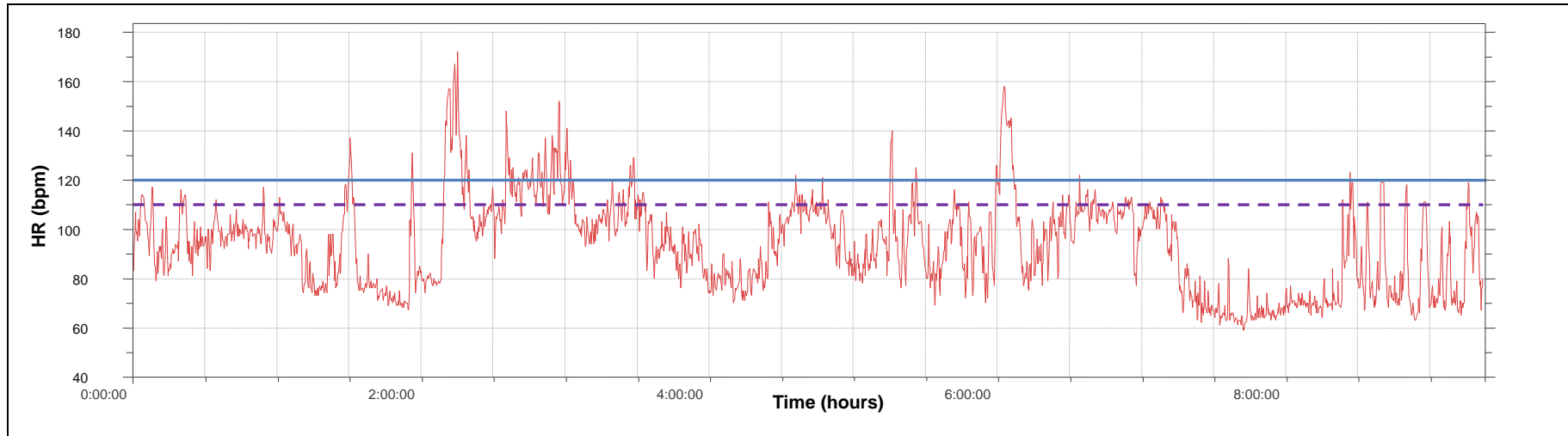
category group, group III (Table 10). Mean HR and HR<sub>MAX</sub> was both higher for the participant who failed the assessment, while mean oral temperature was lower by 0.1 °C. The participant, who failed, had a marginally higher % HR ≥ 120 bpm (7.4 %) than the group that passed (6.1 %) the FWC (22). Comparing the total cumulative heart beats per shift and across an 8-hour shift, the participant who failed, once again had a higher total heart beats than that of the rest of group III participants. Neither group surpassed the maximum proposed cumulative total heart beats. The persons who passed the PWC assessment had a higher mean total and percentage weight loss than the employee who failed.

Figures 4 and 5 are used to illustrate the differences between the real-time HRs of a person who met with the requirements of both the PWC and FWC assessment (group III) and the participant who was unable to meet with the PWC assessment requirements (group III), over an actual shift.

Comparing the two graphs, it can be seen that the HR in Figure 4 (participant who passed FWC and PWC assessment) is very consistent, with small fluctuations across the shift. This graph is a good presentation of self-pacing, the HR staying below the 110 bpm line, with only four HR spikes, where it reaches 120 bpm. A different picture is seen in Figure 5. During the first hour or so, the HR is quite consistent, after which it begins to fluctuate, throughout the rest of the shift. Several HR spikes, across 120 bpm, are followed with sharp declines.



**Figure 4.** Example of a real-time HR over an actual shift for a participant (Group III) who met both the PWC and FWC assessment requirements. The participant had a 0 % HR  $\geq$  120 bpm.



**Figure 5.** Example of a real-time HR, over an actual shift for a participant (Group III) who did not meet the PWC assessment requirements. See Table 10. The participant had an 18.6 % HR  $\geq$  120 bpm across the entire shift.

Correlation coefficients were calculated to determine the relationships between the different physiological markers and between the PWC and FWC assessments, in each group. The PWC and FWC results were used as per Table 8, where the PWC assessment is based on HR while the FWC was allocated a numeric value. The  $r$ -value is an indication of strong correlation ( $r \geq 0.5$ ) which is presented in Table 11. There were several correlations of which a few were statistically significant ( $p \leq 0.05$ ).

**Table 11.** The correlation coefficients between various physiological parameters for each of the groups. [ $HR_{MAX}$  = maximum heart rate (bpm);  $T_{MAX}$  = maximum temperature ( $^{\circ}C$ );  $VO_{2MAX}$  = maximal oxygen consumption (mL/kg/min);  $r$  = correlation coefficient;  $p$  = statistical significance.]

	Group I		Group II		Group III	
	$r$	$p$	$r$	$p$	$r$	$p$
<b>FWC and mean <math>HR_{MAX}</math></b>	0.67 <sup>a</sup>	0.15	- 0.15	0.77	0.96 <sup>a</sup>	0.04 <sup>b</sup>
<b>FWC and mean <math>T_{MAX}</math></b>	0.52 <sup>a</sup>	0.29	- 0.15	0.78	0.62 <sup>a</sup>	0.38
<b>FWC and <math>VO_{2MAX}</math></b>	0.81 <sup>a</sup>	0.18	0.20	0.81	- 0.94 <sup>a</sup>	0.06
<b>PWC and mean <math>HR_{MAX}</math></b>	0.30	0.56	0.73 <sup>a</sup>	0.09	0.73 <sup>a</sup>	0.27
<b>PWC and mean <math>T_{MAX}</math></b>	- 0.72 <sup>a</sup>	0.11	- 0.80 <sup>a</sup>	0.05 <sup>b</sup>	0.36	0.64
<b>PWC and <math>VO_{2MAX}</math></b>	- 0.25	0.75	0.37	0.54	- 0.88 <sup>a</sup>	0.11

<sup>a</sup>  $r \geq 0.5$  – strong correlation

<sup>b</sup>  $p \leq 0.05$  – statistical significance

A strong correlation ( $r \geq 0.5$ ) was found between the FWC assessment and mean  $HR_{MAX}$  for group I ( $r = 0.67$ ), group III showing a statistically significant ( $p \leq 0.05$ ) correlation ( $r = 0.96$ ). Both groups I and III also had a strong correlation between the FWC assessment and the mean  $T_{MAX}$ , although neither were statistically significant. Groups I and III both showed strong correlations between the FWC assessment and  $VO_{2MAX}$ , while the correlation for group III ( $r = - 0.94$ ) was negative and marginally significant, which is indicative of a person faring much better in the FWC

assessment, when he had a high  $VO_{2MAX}$ . Both groups II and group III showed a strong correlation between the PWC assessment and  $HR_{MAX}$ , although neither were statistically significant. Groups I and II both had a negative correlation between the PWC and  $T_{MAX}$ , while the correlation for group II was statistically significant. Only one correlation (group III) was found between the PWC assessment and  $VO_{2MAX}$  ( $r = -0.88$ ).

## **Discussion**

Studies have shown that mining jobs are usually a combination of short bursts of heavy physical activities intermixed with low demand tasks (32, 33). This finding is apparent when one looks at the significant disparity between the mean and maximum HRs found during this study (Table 4). The HRs recorded during each shift fluctuated substantially as seen in Figures 4 and 5. It seems that while there are activities of a particularly strenuous nature during a normal work-day, there are also periods of respite, enabling the employees to manage their energy expenditure.

The manner in which the employees are able to adapt physically to their specific work-tasks, in order to preserve energy (self-pace) over the whole work-day is best represented in Figure 1, where the mean HR balances out the highs (strenuous activities) and the lows (respite). At the onset of the study, it was expected group I to have a notably higher mean HR, since their work is unremitting and of a very strenuous nature. This, however, was not the case as the results showed the three groups to have very similar mean HRs across an 8-hour shift, with group I only just above that of groups II and III.

Contrary to Figure 1, Figure 2 represents the mean percentage of time that the HRs for each group, was higher than 120 bpm, across the shifts ( $n = 8$ ). As expected, group I had the highest % HR  $\geq 120$  bpm (Table 4). This is apparent in Figure 2 although group I had the lowest % HR  $\geq 120$  bpm during shift 1 and 8. Group I was also seen to have the highest mean total cumulative heart beats, being the only group to surpass the self-pacing cumulative total heart beats. The only significant difference was found between groups I and III, the highest and lowest total cumulative heart beats, respectively. Although this is not reflective of a true 8-hour shift spent working in the stope, the additional period should not be ignored, since this time (up to 2 hours) is spent travelling to and from the workplace, adding physiological strain to an already draining day.

The mean % weight loss experienced by all of the participants (Table 4), is an indication of mild dehydration, described as a 0.9 – 2.8 % weight loss of the overall body weight. This amount of weight loss during a shift can cause HR to increase by an average of 10 – 18 bpm, making HR a somewhat unreliable measure of energy expenditure (17). Research has also shown that dehydration can affect both physical and cognitive performance, where a 3 – 4 % loss in bodyweight can lead to as much as a 22 – 50 % reduction in work rate (19). Mental performance will start to decline at a 2 % loss of bodyweight and will continue to decline proportionally to every percentage drop in body weight that is brought about by dehydration (18, 19). While this is an especially worrying occurrence in an environment where the water points are sometimes located long distances away from worksites, the fact that urine SG analysis indicated that the participants were considerably dehydrated (31) at the onset of a shift is a further cause for concern. This could mean that some of the participants were far more dehydrated than indicated by the % weight loss.

Group I was the only group whose mean HR had a statistically significant correlation ( $r \geq 0.5$ ) to the mean percentage weight loss experienced. This suggests that the mean HR of group I, caused by the physical intensity of the work, could have been overestimated by as much as 18 bpm, positioning it much closer to the HRs observed for groups II and III (4, 16, 17).

With evaporative heat only being successful to a degree during exposures such as those found in the underground mining industry, it is expected that the body's core temperature and therefore the oral temperature will increase considerably, especially taking into account the nature of the increased activity (12, 14, 16, 34). While none of the groups had mean body temperatures above the upper limit of 38 °C recommended for workers by the World Health Organisation (35), a strong positive correlation ( $r \geq 0.5$ ) was found between the mean HR and mean body temperatures for all of the groups. All of these correlations were statistically significant ( $p \leq 0.05$ ) which lead to the conclusion that mean HR could be overestimated by as much as 10 bpm, for all of the groups (10, 11, 15, 16).

While great emphasis has been placed on the importance of self-pacing in order to manage fatigue, this factor does not stand alone, as shift duration will affect the management of work related fatigue as well. It is said that work related fatigue arises from high risk work in extreme temperatures. Extended shifts can also have health effects, especially where exposure to hazards such as noise and heat exist (36). Although no specific guideline with regards to the regular shift length for stope workers in the South African gold mining industry could be found, the PWC and FWC assessment is based upon an 8-hour work shift (37). The mean shift duration for the

complete sample group came to 10.16 hours, which would give about an 8-hour work day, if one could subtract the  $\pm 2$  hours traveling time. This however is not possible, since traveling is usually done on foot and forms part of the normal work day.

Despite the fact that some employees were unable to meet the minimum requirements set for employees exposed to “very heavy work” (Table 1) during the FWC assessment this was only seen in one compulsory test item (21). Both groups I and II employees are exposed to barring to a certain extent during their normal work activities, although it falls primarily within group II’s specific work tasks. It is of concern that three of the five employees who were unable to meet the requirements of a category B productivity rating in the barring discipline, were part of group II, who are primarily responsible for this task.

Table 9 summarizes the variance between the group who passed and failed the FWC assessment. It was found that the failed group had higher mean values for all of the variables, except that of the shift duration and % weight loss. Since % weight loss for the failed group was not higher than the suggested 0.9 – 2.8 % weight loss as an indication of mild dehydration, it is assumed that HR was not affected by the dehydration (17).  $VO_{2MAX}$  was lower for the group that failed, which is an indication of a lower work rate capacity (5, 38). These variables indicate that the group who failed were not able to self-pace to the same extent as the participants who passed the assessment.

The employee who failed the PWC assessment was not compared with the whole sample group that passed, such as that of the FWC assessment, but rather

compared with the specific work group, group III. As seen with the group who failed the PWC assessment, the participant who failed the PWC assessment had higher mean values for all of the variables, except for % weight loss and oral temperature. The mean % weight loss was not significant enough to affect mean HR (17). The group who passed had a mean HR, HR<sub>MAX</sub> and % HR  $\geq$  120 bpm that was lower than the person who failed. Mean VO<sub>2MAX</sub> was found to be lower for the person who failed the PWC assessment as well. Since this participant is compared with the specific work group to which he belongs, it is clear that the work activities had a much more strenuous effect, than on the rest of the group.

Statistical analysis indicated that there were some strong correlations between the FWC and PWC assessment and the physiological variables; mean HR<sub>MAX</sub>, mean T<sub>MAX</sub> and the VO<sub>2MAX</sub>. While none of these relationships were found between all three groups, at least two groups in each analysis had a strong correlation, except where the PWC assessment and VO<sub>2MAX</sub> were concerned, where a few of these correlations were statistically significant. The strong statistically significant correlation seen between the FWC assessment and mean HR<sub>MAX</sub> indicates that there is a strong relationship between the work related tasks, assessed during the FWC assessment and the effect of the work tasks performed during a normal work day. Although a correlation was seen between the FWC assessment and mean oral temperature, none was statistically significant, which may be an effect of the standardized environment in which the assessments were performed. The negative statistical significant correlation that was found between the FWC assessment and VO<sub>2MAX</sub> for group III, shows an interesting trend, where a person with a higher VO<sub>2MAX</sub> will perform better during the FWC assessment. The correlations found between HR<sub>MAX</sub>

and the PWC assessment for group II and III shows a positive correlation between the HR measured during the shift and that measured during the assessment, although this relationship was not statistically significant. The negative statistically significant correlation that was found between the PWC assessment and mean body temperature (group II) was unexpected, since this relationship indicates that as the mean body temperature falls, the PWC assessment value would increase. This relationship is not supported in the literature where increased body temperature could lead to increased HR as well (10 – 12).

## **Conclusions**

The deep underground gold mining industry is arguably one of the toughest work environments one can find, pairing strenuous work with a hot, humid and very treacherous environment. One would expect that this would greatly affect the workers' physical capacity to complete the necessary work tasks, but it was found not to be the case.

While there were several employees that had a high mean  $HR_{MAX}$ , none of the mean HRs of the sample groups were higher than the sedentary or self-pacing rate of 110 bpm (3), indicating the employees' ability to alternate between heavy and lighter tasks, in order to reduce energy expenditure. This ability is distinctly visible in Figure 4. Previously it was suggested that group I had the most physically demanding tasks within the sample group. While the results showed them to have the highest mean HR, it could be attributed to the various physiological variables, such as dehydration and high oral temperature, which is known to influence mean HR (4, 7, 8). Even without this overestimation, groups I, II and III had a quite similar mean HR across an 8-hour shift (Figure 1), suggesting that the employees adapted to the demands of

the specific work tasks and the environment in such an extent, as to manage energy expenditure, i.e. self-pace.

Considering the % HR  $\geq$  120 bpm and the total cumulative heart beats, group I did have more HR spikes, where heavy tasks were performed, but these were usually followed by a short respite (Figure 4). Group III, considered to the less taxing work of the three groups, had a statistically significant lower total cumulative heart beats.

As predicted in the literature there were several correlations between the mean HR and % weight loss and mean temperature respectively (4, 9, 12, 15, 34, 39). The effect of mean dehydration on mental performance should be investigated further, especially its effects in a hazardous environment such as that of the underground gold mining industry (18, 19).

The results showed that the mine workers were subject to lengthy shifts, most of which were spent within a very hot, restricted and demanding environment. Although it is known that this type of circumstance can lead to work related fatigue (36), no research could be found specific to the mining environment. Results in other studies showed that long work hours could be linked to adverse health effects such as cardiovascular disease and fatigue (40). A study which was conducted over a two week period focusing on the adverse health effects associated with long work hours on a large scale construction site (41), found no signs of an increased physical exertion or fatigue build-up across the period. Whether this applicable to the mining environment is unknown and further research into this is suggested.

The FWC and PWC assessments take place in a standardized environment in order to exclude the effect of ambient temperature on the measurement of physiological effort (42). Since this is so different from the true working environment, it was believed that these assessments will be unable to give a true reflection of the workers energy expenditure and ability to cope with strenuous day to day work activities. Due to the various correlations (Table 11) which were found between the FWC and PWC assessments and  $T_{MAX}$ ,  $HR_{MAX}$  and  $VO_{2MAX}$ , it is suggested that there is a relevant relationship between the real life situation and standardized laboratory setting. However, it is suggested that inter-individual differences in energy costs for specific tasks as well as the dissimilarities in the day to day structure should be considered, since tasks that were labelled “heavy”, might take up only a very small fraction of an 8-hour shift (43).

Furthermore, it was interesting to find that the comparison between the employees who failed the FWC and PWC assessment and those who passed, showed a marked difference in performance, with the groups that passed faring better in each of the measured variables, i.e. lower mean HR and  $HR_{MAX}$  and a higher  $T_{MAX}$ . It can, therefore, be assumed that passing the FWC and PWC do give a fair assessment of whether an employee will be able to cope with the underground environment and the tasks that go along with it. Another explanation may be that the employees who passed are able to self-pace better, because of a greater amount of experience, having perfected more energy efficient ways of performing strenuous tasks.

Although the study sample was small, some significant correlations were found, especially concerning the relationship between the FWC and PWC and the real time situations that they are based upon. The feasibility of repeating this study on a larger

scale should be investigated, taking into account the effect of dehydration on cognitive function, the physiological effect of extremely long shift durations, and whether there is an accumulative effect over a period of a week.

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# **Chapter 4**

## **GENERAL CONCLUSIONS**

## **4.1 General conclusions**

### **4.1.1 Introduction**

The underground gold mining environment is a challenging work environment, where strenuous work tasks have to be performed in a harsh environment with high ambient temperatures and humidity within restricted work sites. Considering this statement, it would be expected to find that employees working in this type of environment would struggle through a work day, showing high amounts of physiological strain.

It was set out to show and compare the physiological strain workers in these environments are exposed to. This was done through measuring HR throughout the working day, taking oral temperature and calculating the amount of weight loss as a determinant of dehydration. Each of the workers who participated, had to have undergone and passed a FWC and PWC assessment, used as a measure of whether employees are able to withstand the strain of the work tasks that have to be conducted. These results were also compared to the mean HR measured, to determine the assessments' functionality as an indicator of the ability to cope with the underground environment.

### **4.1.2 Conclusions**

The measured values of mean HR, mean temperature and even percentage weight loss were used as an indication of employees' exposure to the very harsh conditions and heavy work that forms part of day to day routine of workers in the underground gold mining industry.

Though it was found that various employees showed high mean  $HR_{MAX}$  and % HR above 120 bpm, none of the sample groups had a mean HR higher than the sedentary work rate of 110 bpm (1). This means that although the employees are exposed to very strenuous conditions, it appears they have been able to adapt by alternating between tasks of a very heavy nature and lighter tasks, in a manner known as self-pacing. This is apparent when comparing the high mean  $HR_{MAX}$  values to the mean HR, while looking at the HR over a normal shift.

Comparing the HR for groups I, II and III it is seen that the groups had very similar HR's over an 8-hour shift, group I only had a slightly higher mean HR, as would be expected taking in to consideration the nature of their work. It was suggested that group I had the most physically demanding tasks within the sample group. This was proved to be true when one looks only at the HR, which shows group I to have the highest mean and maximum HR, the highest %  $HR \geq 120$  bpm and the highest cumulative heart beats. Group III considered as having the least taxing work of the three groups, had a statistically lower %  $HR \geq 120$  bpm. One cannot judge HR separately, as several other factors, such as core temperature and dehydration, can influence it (2 – 4).

When core body temperature begins to increase, due to high ambient temperature and work load, mechanisms of heat loss begin to set in (3, 5). Non-evaporative heat loss is hampered, causing the body to become increasingly reliant on evaporative cooling (6, 7). Evaporative heat loss is only successful to a certain extent during exposure to high humidity, like that which is found within the mining environment. Therefore, taking into

account the fact that the cooling mechanism is unreliable and the nature of the work that is done, the body's core temperature would increase considerably (8, 9). Interestingly, the participants core body temperatures did not increase as much as one would have expected, showing that they are well acclimatized to their work environment. A strong statistically significant positive correlation was seen regarding all of the groups, which could have led to an overestimation of HR of as much as 10 bpm for all of the groups (10 – 12).

During the planning phases, the various ways in which to measure core body temperature were investigated. Methods such as esophageal and rectal temperature measurement were discarded, due to it being invasive and unpleasant (14). Oral temperature which was chosen as the least uncomfortable and non-invasive method, proved difficult to measure at precise intervals due to the constricted work conditions and the random way in which the work was structured. The use of CorTemp™ ingestible core body temperature sensors was investigated at the time as well, since it is able to give an accurate real-time measurement of core body temperature. This method was rejected due to the sensors having to pass through the digestive system, before another probe was ingested (13, 15). In future studies it would be suggested to make use of this more invasive method of measuring core body temperature. These sensors are ingested, therefore giving the most accurate core body temperature in real-time, which is much more comparative to HR (13, 15).

All of the participants were mildly dehydrated at the end of the shifts. Mild dehydration is indicated by a 0.9 – 2.8 % weight loss of the overall body weight during a shift. This

amount of weight loss can cause HR to increase by as much as 10 – 18 bpm (16). HR may, therefore, be a somewhat unreliable measure of HR and the weight loss effect should be taken into account when considering HR. Dehydration is also known to affect physical and mental performance, causing up to a 50 % reduction in work rate (17, 18). The urine SG indicated that most of the employees were already substantially dehydrated at the onset of their shifts (19). This could mean that some of the participants were far more dehydrated than indicated by the % weight loss. This is a cause for great concern, since these participants work in a dangerous environment where they have to be alert at all time. The long distances to and from potable water points, should also be investigated, since the workers will rather focus on finishing their work tasks than taking the time to fetch water.

Only one group (group I) showed a statistically significant positive correlation between mean HR and % weight loss. This would indicate that the mean HR for group I may have been overestimated up to 18 bpm (3, 10). This could indicate that group I had a much lower mean HR, positioning it in the same range as those of group II and III.

All of the groups were exposed to very long shift durations. Although no studies were found specific to the mining environment, the results of studies done on long work hours showed that it could be linked to adverse health effects such as cardiovascular disease and fatigue (20). Although a study which was conducted over a two week period focusing on the adverse health effects associated with long work hours on a large scale construction site (21), found no signs of an increased physical exertion or fatigue build-up across the period. Whether this is applicable to the mining environment is unknown.

Although the FWC and PWC assessment takes place in a standardized environment, several correlations were found between the assessments and  $T_{MAX}$ ,  $HR_{MAX}$  and  $VO_2$  max. This suggests a relevant relationship between the real life situation and the homogenous laboratory setting. However, these assessments do not take into account the inter-individual differences in energy costs for specific tasks, or the dissimilarities in the day to day structure. Some employees may only spend a very small fraction of an 8-hour shift doing tasks that was labelled as “heavy” (22).

Comparing the employees that passed the FWC and PWC assessment, to those that failed showed a marked difference in their respective performances. The groups that passed had a lower mean HR and  $HR_{MAX}$  and higher  $VO_2$  max. It may, therefore, be assumed that as hypothesized, the FWC and PWC assessments provide a valid evaluation of an individual’s work capacity and potential to cope with the varying demands of underground work.

Although the study sample was small, some significant correlations were found, especially concerning the relationship between the FWC and PWC and the real time situations that they were based upon.

## **4.2 Limitations**

There were a few limitations that were identified during and after the completion of this study. During the underground sampling, there was only one person to complete all the temperature measurements, check the heart rate monitors and note the work activities.

Because of the participants' movements to and from and around the work site in order to complete their duties, it wasn't possible to observe each and every one. Temperature measurements could also not be taken as punctually as required. A larger observation team should be considered in future studies of this nature.

In order to calculate the exact dehydration experienced during the work day, the amount of fluid ingested versus the urinary output should be noted. This was not possible, due to the size of the assessment team.

### **4.3 Recommendations**

Based on the results, it is recommended that the distance of potable water points to work-sites should be investigated and fixed according to a standard.

The FWC and PWC assessments should take into account the inter-individual differences in energy costs for specific tasks. It should also look at the dissimilarities in the day to day structure of different employees, since some tasks may take up only a very small fraction of the 8-hour shift.

FWC assessments should be standardized according to the exposure experienced in the work environment, i.e. humidity and temperature, to give a true reflection of the employees' ability to cope with the underground environment.

The feasibility of repeating this study on a larger scale should be investigated. Ingestible core body temperature sensors should be used in order to receive real-time

core body temperature data. Dehydration should be determined by taking into account the amount of fluid ingested during a shift in conjunction with the % weight loss experienced.

Possible future studies to be conducted, can focus on the physiological effects of extremely long shift durations in addition to the strenuous work performed by workers in the mining environment. It should be investigated whether there is a cumulative effect over a period of a week.

The effect of dehydration on cognitive and physical function should be investigated, taking into account the type of work tasks performed in the underground environment. The effect of dehydration on productivity and the emphasis that is placed on high production should be incorporated.

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# **Chapter 5**

## **APPENDICES**

## 5.1 Appendix A:

Table 1. The job categorization for in service employees (1).

Category	Type of Work	Criteria
<p><b>Category A</b></p> <p><b>PWC Test</b> ≤110 bpm</p> <p><b>FWC Test</b> Minimum requirements: Max. load handling: 30 kg Frequent lifting: Cat B Barring: Cat B</p>	<p><b>Very Heavy</b></p>	<p><b>Manual Material Handling:</b> Consists of 34-66% of the work shift (daily exposure).</p> <p><b>Work Environment:</b> Manual material handling takes place in restricted work environments (ceiling heights of 0.850m - 1.5m).</p> <p><b>Heat Exposure:</b> Daily exposure to high environmental heat loads for more than 34% of the work shift.</p> <p><b>Production / Non Production Related:</b> Work tasks are imposed by a process (directly linked to production).</p>
<p><b>Category B</b></p> <p><b>PWC Test</b> 111 – 120 bpm</p> <p><b>FWC Test</b> Minimum requirements: Max. load handling: 30 kg Frequent lifting: Cat B Barring: Cat B</p>	<p><b>Heavy</b></p>	<p><b>Manual Material Handling:</b> Consists of 34-66% of the work shift (daily exposure).</p> <p><b>Work Environment:</b> Manual material handling takes place in unrestricted work environments.</p> <p><b>Heat Exposure:</b> Daily exposure to high environmental heat loads for more than 34% of the work shift.</p> <p><b>Production / Non Production Related:</b> Work tasks are imposed by a process (directly or indirectly linked to production).</p>

<p><b>Category C</b></p> <p><b>PWC Test</b> 121 – 135 bpm</p> <p><b>FWC Test</b> Minimum requirements: Max. load handling: 30 kg Frequent lifting: Cat C-upper Barring: Cat C-upper</p>	<p><b>Moderate</b></p>	<p><b>Manual Material Handling:</b> Load handling consists of less than 34% of the work shift on a daily basis or more than 34% of the work shift on an occasional basis.</p> <p><b>Work Environment:</b> Unrestricted work environments or supervisory work in restricted environments.</p> <p><b>Heat Exposure:</b> Occasional exposure or daily exposure in case of supervisory work.</p> <p><b>Production / Non Production Related:</b> Work tasks indirectly linked to production.</p>
<p><b>Category D</b></p> <p><b>PWC Test</b> 136 – 150 bpm</p> <p><b>FWC Test</b> Minimum requirements: Max. load handling: 25 kg</p>	<p><b>Light</b></p>	<p><b>Manual Material Handling:</b> Load handling consists of less than 34% of the work shift - occasional load handling.</p> <p><b>Work Environment:</b> Unrestricted work environments and/or occasional exposure to restricted work areas.</p> <p><b>Heat Exposure:</b> Occasional exposure.</p> <p><b>Production / Non Production Related:</b> Work tasks indirectly linked to production.</p>

<p><b>Category E</b>  <b>PWC Test</b>  <math>\leq 170</math> bpm  Taking age and weight into consideration</p>	<p><b>Roaming</b></p>	<p><b>Manual Material Handling:</b>  No external workloads more than 5kg required other than wearing PPE.</p> <p><b>Work Environment:</b>  Unrestricted.</p> <p><b>Heat Exposure:</b>  Low exposure to heat.</p> <p><b>Production / Non Production Related:</b>  Not linked to production.  ie. Physical demands essentially restricted to walking, climbing or crawling, wearing prescribed PPE but not transporting any equipment etc.</p>
<p><b>Category F</b>  <b>PWC Test</b>  No requirement, consider the entire profile of the individual</p>	<p><b>Sedentary</b></p>	<p><b>Manual Material Handling:</b>  Load handling limited to loads of up to 5kg, occasional exposure only.</p> <p><b>Work Environment:</b>  Unrestricted. Work tasks take place in a seated/standing work position for at least 50% of the work shift.</p> <p><b>Heat Exposure:</b>  Not exposed to heat.</p> <p><b>Production / Non Production Related:</b>  Not linked to production.</p>

**5.2 Appendix B:**

**Informed Consent**

***Title of the project:***

Some physiological effects of deep underground mining and the relationship with Physical Work Capacity and Functional Work Capacity assessment outcomes.

I, the undersigned

..... (full names)

listened to the information on the project and I declare that I understand the information. I had the opportunity to discuss aspects of the project with the project leader and I declare that I participate in the project as a volunteer. I hereby give my consent to be a subject in this project.

I indemnify the University, also any employee or student of the University, of any liability against myself, which may arise during the course of the project.

I will not submit any claims against the University regarding personal detrimental effects due to the project, due to negligence by the University, its employees or students, or any other subjects.

All the subjects used in the study (individual signed consent forms available on request) (Signature of the subject)

Signed at ..... on .....

**Witnesses**

1. ....

2. ....

Signed at ..... on .....

### **5.3 References**

1. Hofmann T. Guidelines on the interpretation of RFA test results with regards to in-service employees. Rehabilitation and Functional Assessment Joint Venture. 2009. Reference code: RFA/PROC/02.