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Evaluation of heat strain experienced by furnace workers at an iron smelter.

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Mini dissertation submitted in partial fulfilment of the requirements for the degree Magister Scientiae at the Potchefstroom Campus of the North-West University.

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Author's Contribution

This study was planned and executed by a team of researchers. The contribution of each of the researchers is depicted in Table 1.

Table 1: Research team

NAME	CONTRIBUTION
Mrs. C. Westcott	• Personal and environmental sampling. • Literature research, statistical analysis and writing of article.
Prof. F.C. Eloff	• Supervisor • Assisted with designing and planning of study, approval of protocol, reviewing of the dissertation and documentation of the study and analysis and interpretation of results.
Mr. J.L. du Plessis	• Assistant-supervisor • Assisted with approval of the protocol, interpretation of the results and reviewing of the documentation of the study.
Mr. J.N.R. Joubert	• Assistant-supervisor • Assisted with approval of the protocol and reviewing of the documentation of the study.

The following is a statement from the supervisors that confirms each individual's role in the study:

I declare that I have approved the article and that my role in the study as indicated above is representative of my actual contribution and that I hereby give my consent that it may be published as part of Corli Westcott's M.Sc (Occupational Hygiene) dissertation.

Prof. F.C. Eloff | Mr. J.L. du Plessis | Mr. J.N.R. Joubert

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List of Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
bpm	Beats per minute
CT	Core temperature
DB	Dry bulb
GT	Globe temperature
HR	Heart rate
ISO	International Organization for Standardization
M	Metabolic range
MRT	Mean radiant temperature
MWH	Mega watt hour
NIOSH	The National Institute for Occupational Safety and Health
PSI	Physiological Strain Index
RPE	Ratings of Perceived Exertion
SD	Standard deviation
t_{ac}	Auditory canal temperature
t_{or}	Oral temperature
t_{re}	Rectal core temperature
t_s	Oesophageal temperature
t_{ur}	Urine temperature
USG	Urinary specific gravity
WB	Wet bulb
WBGT	Wet Bulb Globe Temperature

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Preface

Most of our time during the day is spent in our working environment. Every working place has different challenges and obstacles that the worker are faced with. One of the main challenges industrial furnace workers have to cope with is heat. How heat is tolerated by a worker will differ for each individual. The objective of this study was to evaluate heat strain experienced by furnace workers in their uncontrolled, every day working environment, by means of physiological as well as environmental monitoring.

Abstract

Background: Any working environment where industrial processes create heat, the worker is potentially exposed to heat-related illnesses because of the increase in thermal load from the environment. For these workers to work a full 12 hour shift, without developing any heat illnesses, their body temperatures must be kept within a narrow range of 1 to 2°C (Joubert and Bates, 2008). Body temperatures substantially higher than optimal temperatures (36.5-37.5°C) may cause a decrease in the mental and physical performance of workers. **Objectives:** To evaluate the heat strain experienced by furnace workers at an iron smelter. The evaluation will include an analysis of data for the full period of the shift (8 hours or 12 hours), as well as the high risk periods (window periods). These window periods consist of the tapping and cleaning time periods. **Methods:** Intra abdominal core temperature was measured by means of a miniature data logging transponder for the duration of the shift. This sensor transmits a wireless signal to a recorder worn on the worker's waist. This method provides continuous measurement of core temperature with limited work interference and no physical annoyance. Heart rate was measured with Polar heart rate transmission straps and hydration by means of Urinary Specific Gravity (USG). The Physiological Strain Index (PSI) was calculated using heart rates and core temperatures. Environmental temperatures on the tap floor were measured with a Heat stress instrument and 150 mm Globe for measuring radiant heat. **Results:** Results indicated that cleaners and tappers of the 8h and 12h shift experience moderate strain. Subjects were adequately hydrated and mean core temperatures did not exceed the limit of 38.5°C for acclimatized individuals. Mean $WBGT_0$ values did not exceed the limit as given in ISO 7243, namely 26 for cleaners and 28 for tappers. An analysis off each individual's data indicated inter-individual differences. The group showing the highest amount of strain also had the highest mean BMI. **Conclusions:** When evaluating heat strain it is important to evaluate each individual's physiological indicators and not just general environmental conditions. A subject's strain can be limited by applying adequate hydration, acclimatization, work-rest ratios and engineering control measures. **Recommendations:** Depending on the severity and intensity of heat strain there are certain general- and job specific controls that should be applied to limit heat

strain. Always consider and include short term exposure in the investigation and not just mean values for the day.

Opsomming

Agtergrond: Enige werksomgewing waar hitte gegenereer word deur industriële prosesse word werkers potensieel blootgestel aan hitte siektes. Dit vind plaas as gevolg van 'n verhoogde termiese lading vanaf die omgewing. Om die werkers instaat te stel om 'n volle 12 uur skof te kan werk, sonder om enige hitte siektes op te doen, moet hul liggaamstemperature binne grense van 1 tot 2°C gehandhaaf word (Joubert en Bates, 2008). Indien liggaamstemperatuur hoër styg as optimale temperature (36.5-37.5°C) sal dit tot verlaagde verstandelike en fisiese funksionering lei. **Doelwitte:** Om die hitte stremming wat oond werkers by 'n yster smelter ervaar te evalueer. Hierdie evaluasie sal 'n analise van data vir die volle tydperk van die skof (8 ure of 12 ure) sowel as die hoë risiko vensterperiodes insluit. Hierdie venster periodes bestaan slegs uit die tye wat werkers tap of skoonmaak. **Metodes:** Kerntemperatuur was intra-abdominaal gemeet deur middel van 'n klein sensor wat oraal ingeneem is, en data na 'n kompakte opnemer gestuur het. Hierdie opnemer is aan die gordel van die werker gedra. Hierdie metode verskaf konstante meting van kerntemperatuur met minimale inmenging en versteuring by die werker. Hart tempo is gemeet deur middel van Polar hart tempo transmissie bande terwyl hul hidrasie vlakke bepaal is deur te kyk na soortlike gewig van die uriene. Hart tempo's en kerntemperature is gebruik om die Fisiologiese Stremmings Indeks te bereken. Op die tapvloer is omgewingstemperature gemeet deur gebruik te maak van 'n Hitte stres instrument en 150 mm Swart Bol. **Resultate**: Daar is gevind dat tappers en skoonmakers matige stremming ervaar tydens die 8 uur skof en 12 uur skof. Werkers was ook voldoende gehidreer terwyl hul gemiddelde kerntemperature nie the limiet vir geakklimatiseerde werkers (38.5°C) oorskry het nie. Gemiddelde WBGT waardes het verder ook nie die limiete (26 vir skoonmakers en 28 vir tappers), soos gegee deur ISO 7243, oorskry nie. By nadere ondersoek van elke individu se data was inter-individuele verskille opmerklik. Die groep wat die hoogste stremming getoon het, het ook die hoogste gemiddelde BMI getoon. **Gevolgtrekking:** Wanneer 'n hitte stremming evaluasie onderneem word, is dit noodsaaklik om elke individu se fisiologiese parameters te meet en nie net die algemene omgewings toestande waarin hulle werk nie. Hitte stremming kan beperk

word deur te sorg vir voldoende hidrasie, akklimatisasie, werk-rus verhoudings en ingenieurs beheermaatreëls. **Aanbevelings:** Afhangende van die mate en intensiteit van hitte stremming is daar sekere algemene- en werkspesifieke beheermaatreëls wat toegepas kan word om stremming te verminder. Dit is verder ook belangrik om korttermyn blootstelling in die ondersoek in te sluit, en nie net gemiddelde waardes vir die dag te bereken nie.

CHAPTER 1: INTRODUCTION

General Introduction

1.1 Introduction

Any working environment where industrial processes create heat, the worker is potentially exposed to heat-related illnesses because of the increase in thermal load from the environment. For these workers to work a full 12 hour shift, without developing any heat illnesses, their body temperatures must be kept within a narrow range of 1 to 2°C (Joubert and Bates, 2008). Body temperatures substantially higher than optimal temperatures (36.5-37.5°C) may cause a decrease in the mental and physical performance of workers. It is therefore important to determine the magnitude of thermal stress in an environment, as well as the individuals' physiological strain experienced in order to increase health and productivity (Rodahl, 2002).

Heat stress can be defined as the net load the body experience as a result of metabolic heat production, clothing requirements and external environmental factors, such as air temperature, humidity, air movement and radiant heat. Heat strain can be defined as the physiological effect of heat stress on the body (Kielblock, 2001; ACGIH, 2008). The body will respond to heat strain experienced and will try to produce heat loss in order to achieve thermal balance (ACGIH, 2008).

According to Joubert and Bates (2008), the main indicators used to determine heat strain include body core temperature, heart rate, sweat loss and urine specific gravity for hydration status. All of the indicators can easily be determined under laboratory conditions, but conducting a survey in order to determine it in the field makes it far more difficult (Joubert and Bates, 2008). Work activities, especially time constraint activities, and real-time circumstances such as non-scheduled lunch hours create challenges when it comes to measuring indicators.

The nature of work done by furnace workers presents problems in accurately determining their physiological strain. Protective clothing worn, especially by tappers, makes it difficult, even impossible to use methods, such as oral-, rectal- or tympanic temperature. Other challenges include the influence of local heat exchanges and radiation heat, work interference and annoyance to the worker (ISO 9886, 2004).

The measurement of intra-abdominal core temperature is done by means of swallowing a miniature sensor which transmits a wireless signal to a recorder worn on the worker's waist. This method provides continuous measurement of core temperature with limited work interference and no physical annoyance. In the present state of knowledge the measurement seems to be unaffected by changes in the environment, except for the effect of radiant heat on the abdomen (ISO 9886, 2004). The acquired measurements can be compared and interpreted by means of standards and relevant indices.

Due to the lack of Occupational Exposure Limit values (OEL) and other South African documentations on heat, data will be compared to reference values given in the American Conference of Governmental Industrial Hygienists (ACGIH) and International Organization for Standardization (ISO) standards.

1.2 Objectives

The aim of the study is to evaluate the heat strain experienced by furnace workers at an iron smelter. The evaluation will include an analysis of data for the full period of the shift, as well as the high risk window periods. These window periods consist of the tapping and cleaning time periods. The exposure of workers during the 8h and 12h shift will be compared as well as the tappers and cleaners. This will be achieved by measurement of the following indicators:

a) Continuous full shift and window period variation in core temperature.
b) Continuous full shift and window period variation in heart rate.
c) Hydration levels of workers before and after shift by means of specific gravity in urine.
d) Determining the workers' exposure to radiation heat as well as the Wet Bulb Globe Temperature (WBGT).
e) Ratings of perceived exertion (RPE).
f) Recommendations with regards to the control of exposure will be given i.e., engineering controls, administrative controls and personal protective equipment.

1.3 Basic Hypothesis

Furnace workers are exposed to a high amount of heat strain which could lead to negative physiological effects and health risks.

1.4 References

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CHAPTER 2: LITERATURE STUDY

Literature Study

A literature review was completed to investigate the circumstances, heat and activities occurring daily at an iron smelter. This encompasses the basic smelting operations.

When the body is exposed to high levels of heat, certain physiological mechanisms are responsible for controlling core body temperature with the purpose of maintaining homeostasis in the body. These mechanisms and processes will be discussed.

The indices relevant to the study and necessary to determine the heat stress or strain individuals are exposed to, are included in this chapter. Variables such as acclimatization, dehydration and the effect of clothing on heat tolerance were also included.

In summary, heat related disorders and the effects and dangers thereof will be reviewed.

2.1 Iron smelting operations

Heavy minerals can be mined from sand by means of open-cast mining activities. Primary and secondary concentration of these minerals can produce magnetic and non-magnetic concentrates, namely ilmenite, rutile and zircon. Ilmenite, being the magnetic concentrate, is used in smelting operations. Anthracite is added to the furnace where the endothermic reduction of ilmenite results in two products, namely iron with a carbon content of 2.5% and titania slag with a Titania oxide content of 86%. These products are tapped at temperatures between 1750 °C (titania slag) and 1450 °C (iron) (Gous, 2006).

In order to tap the iron or slag from the furnace, the tap hole is lanced open by tappers and slag or iron is tapped separately from the furnace. The cleaners are responsible for clearing the launder before the next tap. Both of these groups of workers are exposed to high temperatures and radiant heat and together with the intense labour they perform, could easily lead to heat related disorders and physiological changes.

2.2 Physiological background

To perform daily tasks and activities, required energy is released during metabolic processes. Most of such energy is transferred to heat and regulates core body temperature (Youle, 2005).

Body internal temperature needs to be kept within a narrow range in order to achieve a state of well being. This will depend on the balance between the external environment and net load of heat produced internally due to metabolic processes needed to sustain life (Corleto *et al.*, 2001). Thermal homeostasis can be defined as the process responsible for the regulation of core body temperature within a narrow range in order to maintain normal functioning of the body (Guyton and Hall, 2006).

Core body temperature should be kept within 37°C ± 1°C (AGCIH, 2008). It refers to the temperature of tissues in the body that is unaffected by changes in temperature on the surface tissues, including the brain. The core tissues are located deep within the body to ensure a stable temperature (Parsons *et al.*, 1999; ISO 9886, 2004).

The physiological mechanisms responsible for thermoregulation include the hypothalamus and nervous system. The rate of sweating is controlled by the parasympathetic nervous system, whereas blood flow to the skin and vasodilatation are controlled by the sympathetic nervous system (Wexler, 2002).

The arterio venous anastomoses are vessels concentrated in more distal regions of the skin and heat loss will occur very effectively through them, especially when they are maximally dilated. Distal regions include the hands, feet, nose, lips and ears. The sympathetic nervous system can also cause vasoconstriction of these vessels when the vasoconstrictor neurons are activated. The diameter of the vessel will decrease as a result of venous smooth muscle constriction. The vessels in the proximal skin regions, namely forehead, abdomen, thigh and infraclavicular areas do not contribute greatly to heat loss (Lack *et al.*, 2008).

According to Boulant (2000), there is a hierarchy of structures extending throughout the hypothalamus, brain stem and spinal structures that can sense changes in body temperature (concluded from lesion studies). These structures will then elicit thermoregulatory responses. When the nervous system is intact, the role of the preoptic region becomes more apparent. The preoptic region includes more rostral areas namely, medial and lateral parts of the preoptic nucleus, the anterior hypothalamus and nearby areas of the septum. Body temperatures can be regulated more precisely, especially during exercise or changes in environmental temperatures, when a synaptical connection exist between the preoptic areas and lower brain stem. This allows the nervous system to be more sensitive to subtle changes in central and peripheral temperatures. The nervous system can then select the required appropriate thermoregulatory response.

When thermal homeostasis is not maintained, the body will experience heat stress or cold stress (Guyton and Hall, 2006). A greater amount of heat production than heat loss will result in a rise in core body temperature whereas a greater amount of heat loss will again result in a fall in core temperature (Haveninth, 1999; Miller and Bates, 2007). The functionality of biochemical and cellular processes will be affected by either heat or cold stress (Youle, 2005) and the performance, health and safety of the worker could be compromised (Parsons *et al.*, 1999). If heat loss cannot occur, the body will experience heat strain within 30 minutes (Crockford, 1999). The generation of heat, heat loss and thermal balance are to be discussed in more detail below.

2.3 Heat production

Heat production is the result of metabolic activity (Guyton and Hall, 2006; Havenith, 1999). This is the amount of energy needed to support life functions, for example, respiration and heart function (Havenith, 1999). The rate at which metabolic activity takes place can be affected by the cells' basal rate of metabolism, the extent of muscle activity, hormonal influence, sympathetic stimulation as well as chemical activity in the cells (Guyton and Hall, 2006).

2.4 Heat loss

The deep-set organs of the body are responsible for the majority of heat production. Heat is then transferred to the skin where it is lost to the environment. This heat loss is dependent on two factors, namely the rate of conductance from the core to the skin and the rate of release from the skin to the environment (Guyton and Hall, 2006).

2.5 Thermal balance

The thermal balance existing in the body will be disturbed whenever there is a temperature difference between the body and surroundings. Heat will thus be transferred either to the body or to the environment. This transfer will take place via different transferring processes, namely conduction, convection, radiation and evaporation (Guyton and Hall, 2006; Kielblock, 2001). All of these processes can be combined into a simple equation:

$$M = \pm K \pm C \pm R - E \qquad \text{(Equation 1)}$$

where M is the metabolic heat production, K represents conduction, C convection and R represents radiation. E denotes evaporation of moisture from the skin and respiratory tract. As reflected in the equation, K, C and R can cause either heat gain or heat loss whereas evaporation will only result in heat loss (Guyton and Hall, 2006). The mentioned processes involved in transfer of heat, are to be discussed next.

2.6 Heat transfer mechanisms

2.6.1 Convection

Heat loss due to convection occurs because of heat that is removed from the body by means of air movements (Guyton and Hall, 2006; Kielblock, 2001). This process is dependent on the convection coefficient which represents the temperature gradient between the surface and surrounding air. Skin temperature as well as the velocity of air movement must also be taken into consideration (Schoeman, 1994; Youle, 2005).

Convection can occur by means of two methods: Natural or forced convection (Schoeman, 1994; Youle, 2005). Natural convection occurs when the layer of air surrounding the body surface is heated because of the release of the body's own temperature. This layer is then removed by natural air movements and a new layer of air will form around the body (Schoeman, 1994; Haveninth, 1999). If the air is moving at a higher velocity around the body, convection loss will be greater (Youle, 2005). Forced convection is dependent on the temperature gradient between the skin and surface (Schoeman, 1994) and the velocity of air movement (Youle, 2005). Convective heat loss can account for as much as 15% of total body heat loss if a person is nude in a comfortable room and with no major air movement (Guyton and Hall, 2006).

Heat loss due to convection can be calculated by the following equation:

$$C = h_c (t_s - t_a), \qquad \text{(Equation 2)}$$

where C represents the rate of heat exchange (W/m^2 body surface), t_s the body surface temperature, t_a, the temperature of ambient air and h_c represents the convection coefficient (Kielblock, 2001). Equation 2 can serve as a summary of the factors influencing convective heat loss.

2.6.2 Conduction

The body can lose heat by means of conduction when it comes into direct contact with solid objects, air (Guyton and Hall, 2006) and water (Youle, 2005). Heat loss by means of direct contact with solid objects are usually small (Kielblock, 2001) and amounts to approximately 3% of total body heat loss (Guyton and Hall, 2006; Schoeman, 1994).

Heat transfer from vibrating molecules on the skin to the air will only take place until the temperature gradient between the air and skin is lost. Air convection plays a significant role in removing heated air around the body and replacing it with cooler air. The temperature gradient is then retrieved and further heat loss will take place (Guyton and Hall, 2006).

It may therefore be concluded that the rate of heat transferred by means of conduction will depend on the temperature gradient between the body and contacting material, the thermal conductivity of the material and the surface area of contact (Youle, 2005; Schoeman, 1994).

Conduction, as heat exchange mechanism in the industrial environment, comes into play with the consideration of clothing (Kielblock, 2001). Clothing provides resistance against heat loss and contributes to insulation. The amount of resistance can be expressed by a unit, the 'clo'. 1.0 Clo is the insulation provided by clothing when a person is sitting stationary in air with a temperature of 21°C. This unit indicates the amount of insulation provided by clothing. Air is captured in the material of the clothing and air convection decreases (Youle, 2005). Body clothing loses its potential for providing insulation as soon as it gets wet and this can cause the rate of heat exchange to increase twenty fold (Guyton and Hall, 2006).

2.6.3 Radiation

Heat loss by means of radiation can amount to about 60% of total body heat loss (Schoeman, 1994). Electromagnetic energy is transmitted from the surface (skin) of the person and the amount of emission will depend on the average surface temperature, average temperature of objects surrounding the body and the coefficient of radiant heat exchange. Radiant temperatures are unaffected by air currents (Kielblock, 2001).

Usually no major temperature differences occur between indoor objects. Mean radiant temperature (MRT) is used to describe these conditions (Youle, 2005).

Radiant heat plays an important role in the presence of molten or red-hot steel, where the surface acquires extremely high temperatures. This transpires due to the T^4 relationship which means that the radiant heat from a surface is dependent on the absolute temperature (T) of the surface to the fourth power (Youle, 2005). If radiant temperature in the environment is higher than skin temperature, radiant heat will be transferred from the environment to the skin (Haveninth, 1999). According to Miller and Bates (2007), the skin becomes a channel for heat gain at temperatures above 35 °C and where the radiant load is high.

2.6.4 Evaporation

Evaporation is the loss of moisture from the skin and respiratory tract. Evaporation from the skin occurs by means of diffusion of moisture through the skin (Youle, 2005). This process will occur if a temperature gradient exists between the surface area of the skin and ambient temperature (Schoeman, 1994; Kielblock, 2001). The body can lose up to 10% of heat generated by warming and moistening the cool, dry air inhaled during respiration and then exhaling the warm air (Haveninth, 1999).

A distinction can be made between sensible and insensible evaporation. Sensible heat loss occurs with heat exchange and can be detected by the senses (Youle, 2005; Guyton and Hall, 2006). Sweat that drips from the body or is wiped off does not contribute to heat loss due to evaporation (Youle, 2005). Insensible heat loss occurs regardless if a person sweats or not. Moisture will evaporate from the lungs and skin nonetheless, even without a temperature difference. The body can lose about 450 to 600 ml/day (Guyton and Hall, 2006) (30g/h) (Youle, 2005) due to insensible heat loss.

Evaporation can be an effective means of heat loss when ambient temperatures are higher than skin temperatures. During these circumstances radiation and conduction cause heat gain in the body and heat loss can only take place by means of evaporation (Guyton and Hall, 2006).

2.7 Dehydration

Although sweating is an effective mechanism for heat loss (Guyton and Hall, 2006), fluid losses in sweat may exceed 1 L/h in times of extreme ambient temperatures or during a combination of high temperatures and high humidity levels (Miller and Bates, 2007).

This amount of fluid loss predisposes an individual to dehydration. Dehydration can be defined as the loss of body fluids (Wilmore and Costill, 2004) that can lead from a state of euhydration to hypohydration (Parsons, 2002). During this state of hypohydration the person will experience impaired endurance performance and a decrease in exercise tolerance during long-term activities (Wilmore and Costill, 2004).

If not adequately replaced, the loss in fluid and electrolytes can lead to manifestations of heat illnesses. As a result of dehydration, the decrease in tissue perfusion and cellular dehydration can lead to an individual experiencing headaches, fatigue or heat exhaustion. Light-headedness and syncope can again result from the decrease in plasma volume (Miller and Bates, 2007). Mental and psychological changes could also occur (Brake and Bates, 2003).

The effect of dehydration on the cardiovascular and thermoregulatory systems is illustrated in Figure 1. Fluid loss will lead to a decrease in plasma volume which in turn will lead to a decrease in blood pressure (Willmore and Costill, 2004). This volume loss of plasma combined with an increase in the osmolality of the extracellular fluid, will cause a fluid shift from the intracellular compartment (Miller and Bates, 2007). Blood flow to the muscles and skin will decrease and the body will try to overcome this decrease in blood flow by increasing the heart rate (Wilmore and Costill, 2004).

As previously discussed, the skin is an important structure for heat loss through the mechanisms of evaporation, convection, conduction and radiation (Schoeman, 1994; Haveninth, 1999). When heat dissipation is impaired, the body will retain heat. Elevated body temperature and heart rate levels will manifest with a 2% loss, or more, in body mass due to dehydration (Wilmore and Costill, 2004).

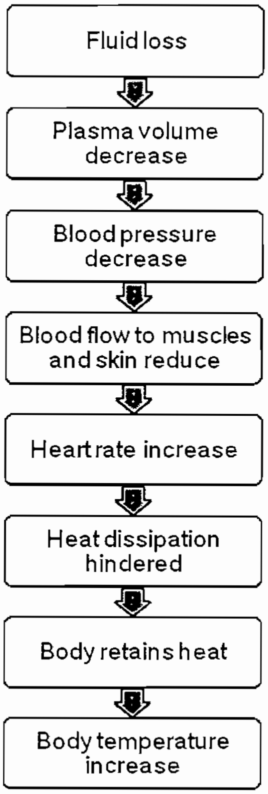

Figure 1: Effect of dehydration on the cardiovascular and thermoregulatory systems.

Brake and Bates (2003) have come to the conclusion that in general, fluid replacement is not sufficient when working under thermal stress. Usually only 50-60% of fluid losses are replaced. This fluid deficit can be attributed to "voluntary dehydration" and "involuntary dehydration".

According to Greenleaf and Sargent (2004), voluntary dehydration can be defined as the delay in complete rehydration following water loss. Passe *et al.* (2007) conducted a study to determine if experienced runners could accurately estimate their fluid intake needed during heat stress. They concluded that voluntary dehydration manifested under experienced runners and the reason can possibly be due to the inability of these runners to judge the amount of fluid needed to prevent dehydration. A predetermined amount of fluid ingestion must therefore be prescribed in order to maintain hydration rather than relying on the self-assessment of the runner.

When a person is hypohydrated and the rate of rehydration is governed by the ability to replenish the solutes lost in sweat (mainly sodium), it can be referred to as involuntary dehydration (Brake and Bates, 2003). It can also be attributed to the fact that 1.5 L of body water can be lost before the thirst mechanism is activated (Wilmore and Costill, 2004). According to Greenleaf (1992), involuntary dehydration can be controlled by the factors stated in Table 1. The psychological component is also important to consider since there is no physiological stimulus necessary for humans to drink fluids.

Table 1: Factors controlling involuntary dehydration (Greenleaf, 1992)

a) Social customs that influence what is consumed.

b) Capacity and rate of fluid absorption from the gastrointestinal system.

c) Level of cellular hydration involving the osmotic-vasopressin interaction with sensitive cells and structures of the central nervous system.

d) Hypovolemic-angiotensin II stimuli (to a lesser extent).

Urinary specific gravity (USG) is a valuable method to determine the absolute hydration status of a person. It can also be used to indicate changes in hydration over a period of time, but it doesn't necessarily change directly linear with water loss. The accuracy of the reading can be influenced by factors such as diuresis as a result of alcohol or caffeine intake, vitamin supplements or some types of drugs (Brake and Bates, 2003).

2.8 Acclimatization

As with dehydration, acclimatization plays an important role in the performance of workers in hot environments (Guyton and Hall, 2006) by enhancing their tolerance of heat stress (ACGIH, 2008; Guyton and Hall, 2006; Willmore and Costill, 2004). It increases thermoregulation by increasing plasma volume and the sweat response (Miller and Bates, 2007). The mechanisms responsible for this process includes an increase in sweat rate, increase in plasma volume as well as a decrease in the excretion of salt in the sweat and urine (Guyton and Hall, 2006; Willmore and Costill, 2004).

When an acclimatized person is working in a hot environment, sweating will increase, especially in the areas responsible for heat dissipation, and the skin temperature will be lower. As a result, blood flow may be shunted more effectively to active muscles, since blood flow to the skin, for heat loss, can be reduced (Willmore and Costill, 2004). A further reduction in blood flow to renal, splanchnic and hepatic organs also increase the blood flow to exercising muscles (Nielsen *et al.*, 1993).

According to Nielsen *et al.* (1993), the acclimation process can be influenced by the type of environment, e.g. a hot and dry or a hot and humid environment as well as the state of physical training.

2.9 Heat stress and Heat strain

2.9.1 Heat stress

Heat stress can be defined as the net load the body experience as a result of metabolic heat production, clothing requirements and external environmental factors (Kielblock, 2001; ACGIH, 2008), such as air temperature, humidity, air movement and radiant heat.

Heat stress is not harmful in mild to moderate capacity, but heat related disorders can occur when heat stress approaches human tolerance limits (ACGIH, 2008).

2.9.2 Heat stress index

Heat stress indices are used to describe and evaluate thermal conditions in order to predict the effect of these conditions on a person. It consists of a combination of all the environmental factors and produces a single number that indicates the stress, strain or risk to a person (Youle, 2005).

2.9.2.1 WBGT Index

The WBGT index was developed with the purpose of defining conditions under which heat injuries may occur during basic and advanced military trainees. In order to control these casualties, safe limits were developed for physical exertion in heat (Parsons, 2006).

The WBGT index is used worldwide and contributes to many standards (Youle, 2005; Kielblock, 2007). It is applicable to the military, industrial, domestic, sporting and commercial contexts (Parsons, 2006). It was developed for traditional work where a long-sleeve shirt and pants are worn (ACGIH, 2008).

The WBGT direct reading instrument determine the four environmental factors that have an effect on heat exchange: radiant heat, ambient temperature, moisture content in the air and wind speed or air flow rate (Schoeman, 1994; ACGIH, 2008). This index has to be used in relationship with core body temperatures not higher than 38 °C and should not be used in isolation (Youle, 2005).

The heat stress a person will experience depends on the internal heat generated due to physical activity or the influence of the environment governing heat transfer between the atmosphere and body. Consequently, the quantity of heat produced inside the body needs to be determined. Metabolic energy is a good estimation of internal heat production for most industrial situations and can be determined either by means of oxygen consumption or by using reference tables (Table 2) (ISO 7243, 1989).

Table 2: Classification of levels of metabolic rate (ISO 7243)

Class	Metabolic rate range, M		Value to be used for calculation of mean metabolic rate		Examples
	Related to a unit skin surface area (W/m^2)	For mean skin surface area of 1.8 m^2 (W)	(W/m^2)	(W)	
0 - Resting	M<65	M<117	65	117	Resting.
1 - Low metabolic rate	65<M<130	117<M<234	100	180	*Sitting at ease:* light manual work; hand and arm work; arm and leg work *Standing*: drill; milling machine; coil winding; small armature winding; machining with low power tools; casual walking (up to 3.5 km/h).
2 – Moderate metabolic rate	130<M<200	234<M<360	165	297	Sustained hand and arm work; arm and leg work (off road operation of lorries, tractors etc.); arm and trunk work; pushing or pulling light weight carts or wheelbarrows; walking at a speed of 3.5 km/h to 5.5 km/h; forging.

Class	Metabolic rate range, M		Value to be used for calculation of mean metabolic rate		Examples
	Related to a unit skin surface area (W/m^2)	For mean skin surface area of 1.8 m^2 (W)	(W/m^2)	(W)	
3 – High metabolic rate	200<M<260	360<M<468	230	414	Intense arm and trunk work; carrying heavy material; shovelling; sledge hammer work; sawing, planning or chiselling hard wood; hand mowing; digging; walking at a speed of 5.5 km/h tot 7 km/h. Pushing or pulling heavily loaded handcarts or wheelbarrows; chipping castings; concrete block laying.
4 – Very high metabolic rate	M>260	M>468	290	522	Very intense activity at fast to maximum pace; working with an axe; intense shovelling or digging; climbing stairs, ramp or ladder; walking quickly with small steps, running, walking at a speed greater than 7 km/h.

The WBGT can be calculated using the following equations:

WBGT = 0.7 WB + 0.3 GT (indoors)   (Equation 3)

WBGT = 0.7 WB + 0.2 GT + 0.1 DB (outdoors)   (Equation 4)

where WB is the wet bulb temperature (natural); GT, the globe temperature and DB is the dry bulb temperature (Youle, 2005; Parsons, 1999). The sun contributes to the value of globe temperature and the outdoor formula takes this fact into consideration (Youle, 2005).

Radiation heat is measured by means of the black globe thermometer. The globe thermometer consists of a hollow copper sphere, matt black in colour, to be able to absorb the radiation heat. A mercury thermometer or thermocouple is placed in the middle of the sphere (Schoeman, 1994).

The temperature in the bulb takes approximately 30 minutes to stabilize whereafter the first reading can be taken. Subsequent readings will be taken with 30 minute intervals. The mean radiation temperature (MRT) can be measured indirectly with the globe thermometer (Schoeman, 1994). With a source of radiant heat present (furnace), the globe temperature will be higher than the dry bulb temperature. If the difference is 1°C or more Equation 4 will be used (Schoeman, 1994).

From the formula it is ascertained that the WBGT index provides most for the wet bulb value (70%). The value can therefore be correlated with a worker wearing saturated clothing in an environment where evaporation can take place freely (Parsons *et al.*, 1999).

ISO 7243 provides reference values (Table 3) for the WBGT index, which, when these values are exceeded, necessitates either the reduction of heat stress in the workplace directly by means of appropriate methods or to conduct a detailed analysis of the heat stress. The reference values are representative of a healthy, physically fit individual clothed conventionally (thermal insulation index I_{clo} = 0.6 Clo).

The values also only allow for a maximum rectal temperature of 38°C.

Table 3: Reference values corresponding to a given situation (ISO 7243)

Class	Metabolic rate range, M		Reference value of WBGT			
	Related to a unit skin surface area (W/m^2)	For mean skin surface area of 1.8 m^2 ^{2}(W)	Person acclimatized to heat (°C)		Person not acclimatized to heat (°C)	
0 - Resting	M<65	M<117	33		32	
1 - Low metabolic rate	65<M<130	117<M<234	30		29	
2 – Moderate metabolic rate	130<M<200	234<M<360	28		26	
3 – High metabolic rate	200<M<260	360<M<468	No sensible air movement 26	Sensible air movement 26	No sensible air movement 22	Sensible air movement 23
4 – Very high metabolic rate	M>260	M>468	23	25	18	20

2.9.2 Heat strain

Heat strain can be defined as the physiological effect of heat stress on the body (Kielblock, 2001; ACGIH, 2008). The body will respond to such strain experienced and will try to produce heat loss in order to achieve thermal balance (ACGIH, 2008).

2.9.2.1 Physiological indicators

In order to determine the strain on the body as a result of heat stress, the following physiological parameters are used in accordance to ISO 9886 (2004) and Parsons *et al.* (1999): body core temperature, skin temperature, heart rate and body mass loss.

2.9.2.1.1 Core temperature (t_c)

Body core temperature should not exceed 38 °C or a rise of 1 °C, whichever comes first (ISO 9886, 2004) for unacclimatized workers or 38,5 °C for acclimatized workers (ACGIH, 2008). A maximum core temperature of 39 °C should not be exceeded. Body core temperature can be determined by the following measurements (ISO 9886, 2004): oesophagus (oesophageal temperature, t_{es}), rectum (rectal temperature, t_{re}), gastro-intestinal tract (intra-abdominal temperature, t_{ab}), mouth (oral temperature, t_{or}), tympanum (tympanic temperature, t_{ty}), auditory canal (auditory canal temperature, t_{ac}) and urine temperature, t_{ur}.

2.9.2.1.2 Skin temperature

Measurement of skin temperature alone is not sufficient for calculating physiological strain, but it does play an important role in determining thermal comfort (ISO 9886, 2004).

2.9.2.1.3 Heart rate

Heart rate can serve as a general indicator of stress experienced by the body (Parsons *et al.*, 1999). A close relationship exist between the rise in heart rate (ΔHR_T) as a result of a rise in t_{cr}. This occurrence is called cardiac reactivity and is expressed in heartbeats per minute and per degree Celsius (beats.min^{-1}.°C^{-1}). Cardiac reactivity can be influenced by two factors: type of exertion (muscular group involved) or the origin of thermal stress be it exogenic (due to the climate) or endogenic (essentially due to the metabolism).

Thus, the greater the ΔHR_T, the greater the thermal strain experienced at that moment (ISO 9886, 2004).

When heart rate is measured over several minutes and it exceeds 180 bpm, after subtracting the worker's age in years, it may also be an indication of heat strain. After the exertion of an activity of great effort, the recovery heart rate should not exceed 120 bpm (ACGIH, 2008). ISO 9886 (2004) indicate an increase of 33 bpm for every 1 °C rise in temperature, with a maximum of 60 bpm.

2.9.2.1.4 Body-mass loss due to sweating (Δm_{sw})

This parameter can be used in a warm environment in order to evaluate thermal strain. The sweat loss includes sweat that evaporates from the skin, sweat dripping from the body or absorbed by the clothing. This parameter is closely related to the risk of dehydration (ISO 9886, 2004; Parsons *et al.*, 1999) and can be used as an indication of the thermal efficiency of clothing (Parsons, 1999).

Unacclimatized workers should not lose more than 1 L of sweat per hour and acclimatized workers not more than 1.25 L/h, with a maximum amount of weight loss of 5% (ISO 9886, 2004).

2.9.2.1.5 Urine Specific Gravity (USG)

USG is dependent on the concentration of solutes in the sample of urine and is used as an indication of the hydration status of a worker. Urine with a high osmolarity (i.e. higher concentration particles), will result in a dark colour and a state of hypohydration (decreased hydration levels) (Joubert and Bates, 2008). With USG the density of urine is compared to the density of distilled water that is fixed as 1.000 at 20 °C (WHO, 2008).

Joubert and Bates (2008) provide a guide to values of USG indicating different levels of hydration. Refer to Table 4.

Table 4: A guide to Specific Gravity Hydration Levels (Joubert and Bates, 2008)

Urine SG level	Risk rating	Hydration rating	Action required
1.000 – 1.021	Low	Adequate hydration	No action.
1.022 – 1.026	Moderate	Hypohydrated	Drink 1 L of water.
1.027 – 1.029	High	Dehydrated	Drink at least 1.5 L of water.
>1.030	Critical	Clinically dehydrated	Unacceptable risk, stop work and drink water until properly hydrated (may take several hours).

2.9.3 Physiological Strain Index (PSI)

The PSI may be used to describe physiological strain on a universal scale of 0 – 10 and is based on two physiological indicators, namely HR and T_{re}. These physiological indicators reflect the strain experienced by the cardiovascular and thermoregulatory systems. The following equation describes the relationship between HR and T_{re} in order to provide a normalized physiological stress index:

$$PSI = 5(T_{re} - T_{re0}) \cdot (39.5 - T_{re0})^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1} \quad \text{(Equation 6)}$$

where, T_{ret} and HR_t are simultaneous measurements taken at any time. T_{re} and HR were assigned with the same weight by using a constant of 5. This index is also limited to the following values:

$36.5 \leq T_{re} \leq 39.5°C$ and $60 \leq HR \leq 180$ bpm

The simplicity of this scale makes it easy to use, 0 representing no strain, and 10 very strenuous physiological conditions. Due to the fact that it is based on HR and T_{re}, the index can be used at any time, even during rest or recovery (Moron *et al.*, 1998).

2.10 Discussion on indicators

Although continuous measurements can be provided with t_{es}, t_{re}, t_{ab} (transducer) and t_{ac}, these indicators are not suitable for use in the workplace due to their interference with working operations (ISO 9886, 2004).

The placement time for the axillary site varies between seconds to 15 minutes (Chaturvedi *et al.*, 2004) and is not accurate to use in working conditions where protective equipment interferes with the placement of the thermometer.

Intra-abdorninal temperature provides a continuous real-time measurement of core temperature, with limited interference in the workplace. This parameter is also reasonably unaffected by ambient temperature conditions, with the exception of strong radiant heat on the abdomen.

Oral temperature is dependent on external conditions. Thermal exchanges by means of convection and evaporation can take place between the buccal mucus membrane and environment when the mouth is open. The temperature in the buccal cavity will then decrease. With the mouth closed, the reading may still be lower. This can be attributed to a decrease in the cutaneous temperature of the face. The presence of strong radiant heat can cause a rise in oral temperature (ISO 9886, 2004).

2.11 The effect of clothing on heat tolerance

Clothing that is water-vapor-impermeable, air-impermeable and thermally insulating prohibit heat loss due to evaporation. Metabolic heat will be generated as a result and a person will experience heat strain even though ambient temperatures are low (ACGIH, 2008; Crockford, 1999). The influence of clothing and the thermal properties of clothing must be considered in order to predict the risk of thermal strain (Parsons *et al.*, 1999).

Clothing provides resistance against heat and moisture loss between the skin and environment. Conduction and radiation are the most significant causes of heat transferal through clothing. The amount of insulation is related to the layer of air enclosed by the clothing which in turn is related to the thickness of the material (volume of fibres) (Haveninth, 1999).

Air movement in the working environment will disturb the still layer of air on the outside of clothing as well as the layer of air on the inside when it enters through openings in the material. The permeability of clothing will have a great effect on air movement. The type and number of clothing layers, the enclosed air layers, clothing fit and the design of clothing is all factors that will determine the effect of clothing on heat stress limits. Maximal exposure time with different types of clothing are given in Table 5 (Haveninth, 1999):

Table 5: Time that a worker can do moderate work in an environment of 37 °C before body temperature reach 38.5 °C (Haveninth, 1999).

Clothing type	Maximal exposure time (min)
Nude	120
Normal work gear, cotton, single layer	90
Protective clothing, cotton, three layers	45
Protective clothing, cotton, waterproof outer layer, total three layers	30
Fully encapsulating clothing, impermeable outer layer	20

2.12 Heat-related disorders

Heat rash, heat cramps, heat exhaustion and heat stroke are all heat-related disorders. These disorders will be discussed in the subsequent section.

2.12.1 Heat rash

Hot humid conditions cause a person to perspire continuously. The sweat pores on the skin's surface may become clogged as a result of the high level of perspiration and become red, swollen and infective. The skin surrounding the pores will swell. To prevent heat rash it is important to allow evaporation of sweat in these conditions (Schoeman, 1994).

2.12.2 Heat cramps

Factors causing heat cramps are complex and include inadequate blood or oxygen provision, cold, hampered muscle excitation, electrolyte deficiency and dehydration (Schoeman, 1994).

According to Kielblock (2001), heat cramps are a misnomer and is not simply caused by salt depletion. The cramping convulsions are not caused by exposure to heat, but are secondary to the respiratory alkalosis caused by hyperventilation. The electrolyte and acid-base balance are disturbed during continuous muscle excitation. A fall in plasma volume will also lead to the occurrence of cramps.

There is a distinction between heat cramps and exertion-induced cramps, the difference being that heat cramps involve individual muscle bundles and not the whole muscle (Kielblock, 2001). The abdominal wall and limbs seem to be the targets of heat cramps (Kielblock, 2001; Wexler, 2002; Bailes and Reeve, 2007). Heat cramps are usually related to the environment, the state of heat acclimatization, onset period, nature of the cramp as well as plasma and urine sodium content (Kielblock, 2001). Heat cramps also occur when a person ceases work and is relaxing (Bailes and Reeve, 2007).

Unacclimatised individuals are especially susceptible to heat cramps. Factors that play a role include, low plasma sodium levels, low urine sodium chloride content and high urinary specific gravity levels (Kielblock, 2001).

Treatment includes moving an individual to an area for rest and the oral ingestion of an 0.1 % saline therapy or an intravenous therapy of 0.5 – 0.1 normal saline solution (Kielblock, 2001).

Schoeman (1994) and Kielblock (2001) agree on the fact that a small amount of salt is lost during profuse sweating. Schoeman (1994) states that the amount of water excreted during intense activities are greater than the loss of salt and therefore the concentration of electrolytes in the blood are higher.

The most dangerous detrimental effect may occur if a high concentration of sodium ions (Na^+) causes an increase in the excretion of potassium ions (K^+) in urine. The potassium ions are necessary for maintaining muscular functions in the body, including the functioning of heart muscle (Schoeman, 1994).

2.12.3 Heat exhaustion

Factors leading to heat exhaustion include dehydration, inadequate distribution of blood during heat stress, or if the person may be suffering from a circulatory defect (Schoeman, 1994; Kielblock, 2001). Kielblock (2001) also states that the key factor for the occurrence of heat exhaustion is a reduction in circulatory blood volume. This implies that insufficient circulation cannot meet the needs for thermoregulation and blood circulation to the skin with diminishing effects on vital organs and skeletal muscles.

Dehydration can act synergistically to heat exhaustion but it may also occur independently from dehydration. This heat related illness is prevalent in unacclimatised workers (Kielblock, 2001).

A person suffering from heat exhaustion will experience the symptoms listed in Table 6. Core body temperature is usually normal or slightly elevated (Kielblock, 2001), but it remains below 40 °C (Bailes and Reeve, 2007; Wexler, 2002).

A distinction can be made between "acute" and "progressive" heat exhaustion. Acute heat exhaustion occurs within a few hours and is mainly characterized by fluid loss. This heat related illness will progress if inadequate dietary electrolyte replenishment persists over a period of days. Progressive heat exhaustion will require rest, body cooling, fluid- and electrolyte replacement (Kielblock, 2001).

Table 6: Symptoms experienced during heat exhaustion (Schoeman, 1994; Kielblock, 2001; Wexler, 2002; Bailes and Reeve, 2007).

General	Thermoregulatory	Circulatory system
• Weakness • Frontal headache • Anorexia • Nausea/vomiting • Faintness/actual fainting • Breathlessness • Thirst • Muscle cramps • Numbness of arms and legs • Fatigue	• Normal/slightly elevated core body temperature not rising above 40 °C. • Normal sweat rate • Pale skin	• Weak pulse • High heart rate • Low arterial blood pressure • Incipient to overt circulatory shock

Treatment of heat exhaustion varies. When a person is unable to continue work or has fainted because of heat exhaustion, the aim of treatment will be to stabilise the circulatory system. Discontinuing muscular function might even be sufficient for uncomplicated cases of heat syncope. Relocation of the individual to a cool environment and sufficient rest will be satisfactory to restore circulatory volume (Kielblock, 2001; Bailes and Reeve, 2007; Wexler, 2002). Along with fluid replacement of 1L/hour including salt replacement (if needed), recovery will take 2 to 3 three hours (Bailes and Reeve, 2007; Wexler, 2002). However, if dehydration was the cause of heat exhaustion, intravenous infusions will be necessary (Kielblock, 2001; Bailes and Reeve, 2007).

2.12.4 Heat stroke

Heat stroke is considered to be the most fatal of all heat related illnesses and one of the few true medical emergencies (Kielblock, 2001; Wexler, 2002; Bailes and Reeve, 2007). This illness has a mortality rate of up to 80% (Kielblock, 2001). If treatment is appropriate and immediate however, most patients (between 90 – 100%) can survive heat stroke (Wexler, 2002).

Heat stroke can be defined as a heat related illness where core body temperature rises to 40 °C or higher (Schoeman, 1994; Bailes and Reeve, 2007) and it may result in tissue damage. The extent of damage to the nervous system, liver and kidneys will determine the condition of the patient. It is therefore important to include parameters of tissue damage, e.g. the assay of tissue enzymes in serum, in the diagnosis of heat stroke (Kielblock, 2001).

Heat stroke can be catagorised into "exertion induced" and "classical" heat stroke (Kielblock, 2001; Wexler, 2002; Bailes and Reeve, 2007). Classical heat stroke occurs with thermoregulatory failure. A rise in body temperature of higher than 41°C is characteristic together with nervous system disturbances and sweat cessation (Kielblock, 2001). Wexler (2002), states that the triad of classic heat stroke include hyperpyrexia, anhidrosis and mental status changes. Exertional heat stroke on the other hand, is due to thermoregulatory overload and atypical signs. It doesn't occur with a fixed pattern and has a very unpredictable onset (Kielblock, 2001). One of the main differences between these two categories is that a person suffering from exertional heat stroke may continue to sweat (Kielblock, 2001; Bailes and Reeves, 2007; Wexler, 2002). Table 7 depicts a more detailed description of the differences between the two categories (Kielblock, 2001):

Table 7: Classical and Exertion-induced heat stroke (Kielblock, 2001)

Characteristics	Heat stroke	
	Classical	Exertional
Age	Older	Young
Occurrence	Epidemic	Isolated cases
Pyrexia	Very high	High
Predisposing illness	Frequent	Rare
Sweating	Often absent	May be present
Acid-base disturbance	Respiratory alkalosis	Lactic acidosis
Rhabdomyolysis	Rare	Common
Disseminated intravascular coagulation	Rare	Common
Acute renal failure	Rare	Common
Hyperuricaemia	Mild	Marked
Enzyme elevation	Mild	Marked

According to Kielblock (2001), elevated serum enzyme levels are a consistent finding in heat stroke. An elevation of aspartate transaminase (AST) can indicate the extent of tissue damage while an elevation of creatine kinase (CK) in the cerebrospinal fluid serves as an indicator of neurological damage. The elevation of AST will also increase lactate dehydrogenase (LD) levels. For this reason serum enzyme assays of LD, CK, AST and ALT (alanine transaminase) are used diagnostically. These enzyme assays also allow for the distinction between classic and exertion-induced heat exhaustion as well as the progression of exhaustion to overt heat stroke.

The two primary treatment methods of heat stroke include whole body ice water immersion and evaporative methods. During whole body immersion, the individual is placed in a tub filled with cold water or ice water and vital signs are monitored. Evaporative cooling entails spraying a patient with water (15^{o}C), while air (45°C) is passed over the body (Wexler, 2002). There were some differences of opinion regarding the best method for hyperthermic cooling. Evaporative methods have been said to provide effective cooling rates and are more sanitary (since there aren't any problems such as diarrhea or vomit in the water which may occur during immersion) and doesn't interfere with patient monitoring and treatments such as intravenous administration of fluids and medications (Clements *et al.*, 2002). Clements *et al.* (2002) have also conducted a study to determine any significant differences between ice water and cold water immersion. They concluded that there is no significant difference and that either method can be used.

2.13 Long term effects of heat strain

According to the CCOHS (2008), long term effects could include kidney, liver, heart, digestive system, central nervous system and skin illnesses. Evidence of these conditions is unfortunately not conclusive.

2.14 Other effects of heat exposure

Studies have been conducted in order to investigate the effect of occupational exposure to high temperatures on infertility of male subjects. Impairment of spermatogenesis has been found in the welding profession, ceramics industry and also among professional drivers. Heat has been found as an independent risk factor for male infertility during a study that included French military population (Sheiner *et al.*, 2003).

A study on the effect of male occupational heat exposure on time against pregnancy showed heat to be a weak risk factor for male subfertility (Thonneau *et al.*, 1997).

2.15 Ratings of perceived exertion

According to Borg (1982), more attention has been given to how people feel, the amount of pains and aches they experience and their perception of the physical work they perform. In order to relate objective findings to subjective or personal symptoms experienced by individuals, it was necessary to quantify the subjective symptoms.

Borg's Ratings of perceived exertion (RPE) Scale is based on the phenomenon that oxygen consumption and heart rate increase linearly with increasing work load. Although this would be a violation of the true growth of perceived intensities, it provides a convenient means for the construction of a scale. Correlations between 0.8 – 0.9 were noted between the rating scores and heart rate.

The RPE Scale consists of a 15-grade scale with scale values ranging from 6 to 20, which can also indicate heart rates varying from 60 to 200 bpm. This correlation should not be taken too literally since it is influenced by factors such as age, type of exercise, environment and anxiety.

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The corresponding author should be identified in the submission. Full postal addresses should be included for all co-authors. A letter consenting to publication should be signed by all authors of a submission and sent to the Editorial Office.

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On request, authors must produce original data for inspection by the editor. Studies that were conducted on human subjects, other than measurements in the course of their normal work activities, have to get approval from a competent ethics committee using the standards of the Helsinki Declaration of the World Medical Association. The ethics committee used must also be named in the paper.

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Manuscripts must be in English and written in a way that is understandable and clear to all. British or American styles and spelling can be used, but it should be used consistently while words and phrases that might not be clear in other parts of the world should be avoided.

6. **Brevity, and supplementary material.**

Regarding the length of the paper, it depends on the subject, but should be as brief as possible and consistent in clarity. 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. If the length of the paper is more than 5000 words, a statement must be included justifying the extra length.

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Papers should generally follow the format of: Introduction, Methods, Results, Discussion and Conclusions. The abstract should include argument and findings and can be arranged under the headings Objectives, Methods, Results, and Conclusions. Keywords should be given after the list of authors.

8. **Survey design.**

Sampling surveys should be planned using modern statistical principles so that the quality of the data is good enough to justify the inferences and conclusions drawn.

9. **Units and symbols.**

SI units should be used and their equivalent in other systems can be given as well.

10. **Figures.**

Figures, photographs, diagrams and charts should be about the same size as will be reproduced in, and font size should be at least 6 point using standard Adobe set of fonts. Fine hairlines should be avoided and clear hatching patterns should be used in preference to solid grey shadings.

11. **Tables.**

Numbering of tables should be consecutively and given a suitable caption, and each table typed on a separate page. Footnotes to tables should be typed below the table and should be referred to by superscript lowercase letters.

12. **References.**

References in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones et al. (1995) if there are more than two authors. References at the end of the paper should be listed alphabetically by name of first author, using the Vancouver Style of abbreviation and punctuation. ISBNs should be given for books and other publications where appropriate.

CHAPTER 3: ARTICLE

Evaluation of heat strain experienced by furnace workers at an iron smelter.

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Keywords: heat strain; furnace workers; physiological indicators; thermal environment

3.1 ABSTRACT

Background: Furnace workers are exposed to extreme temperatures whilst performing their everyday activities. In order to protect the health of workers it is necessary to determine the amount of heat strain experienced in their working conditions. **Objectives:** To evaluate the heat strain experienced by furnace workers at an iron smelter. The evaluation will include physiological and environmental monitoring as well as an analysis of data for the full period of the shift (8 hours or 12 hours), as well as the high risk window periods. These window periods consist of the tapping and cleaning time periods. **Methods:** Intra abdominal core temperature was measured by means of a miniature data logging transponder for the duration of the shift. Heart rate was measured with Polar heart rate transmission straps and hydration by means of Urinary Specific Gravity (USG). The Physiological Strain Index (PSI) was calculated using heart rates and core temperatures. Environmental temperatures on the tap floor were measured with a Heat stress instrument and 150 mm Globe for measuring radiant heat. **Results:** Results indicated that cleaners and tappers of the 8h and 12h shift experience moderate strain. Subjects were adequately hydrated and mean core temperatures did not exceed the limit of 38.5°C for acclimatized individuals. Mean $WBGT_o$ values did not exceed the limit as specified in ISO 7243, namely 26 for cleaners and 28 for tappers. **Conclusions:** When evaluating heat strain it is important to evaluate each individual's physiological indicators and not just general environmental conditions. A subject's strain may be limited by applying adequate hydration, proper acclimatization, work-rest ratios and engineering control measures.

3.2 INTRODUCTION

Iron and slag smelting operations generate extreme temperatures. These products are tapped from a furnace at temperatures between 1750 °C (titania slag) and 1450 °C (iron) (Gous, 2006). In any working environment where industrial processes create heat, workers are potentially exposed to heat-related illnesses because of the increase in thermal load from the environment (Joubert and Bates, 2008). Heat related disorders include heat rash, heat cramps, heat exhaustion and heat stroke, which is classified as one of the true medical emergencies (Stanton *et al.*, 2007).

Heat stress can be defined as the net load the body experience as a result of metabolic heat production, clothing requirements and external environmental factors, such as air temperature, humidity, air movement and radiant heat. Heat strain can be defined as the physiological effect of heat stress on the body (Kielblock, 2001; ACGIH, 2008).

The body will respond to heat strain by increasing heat loss in order to achieve thermal balance (ACGIH, 2008). Heat loss may occur by means of conduction, convection, evaporation and radiation (Youle, 2005). In order to achieve a state of well being, internal body temperature needs to be kept within a narrow range. This will depend on the balance between the external environment and the net load of heat produced internally due to metabolic processes needed to sustain life (Corleto *et al.*, 2001). Body core temperature should not exceed 38 °C or a rise of 1 °C, whichever comes first (ISO 9886, 2004) for unacclimatized workers or 38,5 °C for acclimatized workers (ACGIH, 2008).

Although sweating is an effective mechanism for heat loss (Guyton and Hall, 2006), fluid losses in sweat may exceed 1 L/h in times of extreme ambient temperatures or during a combination of high temperatures and high humidity levels (Miller and Bates, 2007). This amount of fluid loss predisposes an individual to dehydration, which causes impaired endurance performance and a decrease in exercise tolerance during long-term activities (Wilmore and Costill, 2004). As with dehydration, acclimatization plays an important role in the performance of workers in hot environments (Guyton and Hall, 2006) by enhancing their tolerance to heat stress (ACGIH, 2008; Guyton and Hall, 2006; Willmore and Costill, 2004).

ISO 7243 (1989) is specific to hot environments and is based on Wet Bulb Globe Temperatures (WBGT). The WBGT pertains to the evaluation of the effect of heat on man during his work activities. Guidelines are provided for the physical environment.

This index takes the metabolic rate produced during different intensities of labour into consideration. The ACGIH (2008) provides clothing adjustment factors, TLV®

values as well as guidelines for limiting heat strain. ISO 9886: Ergonomics – Evaluation of thermal strain by physiological measurements, provides physical indicators for characterising thermal strain. The Physiological Strain Index (PSI) provides an easy to use scale, ranging from 1 to 10, indicating the strain experienced. On this scale 1-2 indicate no or little-, 3-4 low-, 5-6 moderate-, 7-8 high- and 9-10 very high strain. Both core temperature and heart rate are used in the calculation of PSI (Moron *et al.*, 1998).

According to Joubert and Bates (2008), the main indicators used to determine heat strain include core body temperature, heart rate, sweat loss and urine specific gravity for hydration status. Urinary specific gravity (USG) is a valuable method to determine the absolute hydration status of a person. It can also be used to indicate changes in hydration over a period of time, but it doesn't necessarily change directly linear with water loss (Brake and Bates, 2003). All of the indicators can easily be determined under laboratory conditions, but conducting a survey in the field makes it far more complicated (Joubert and Bates, 2008). Work activities, especially time constraint activities, and real-time circumstances such as non-scheduled lunch hours create challenges when it comes to measuring these indicators.

The aim of this study is to perform environmental and physiological monitoring on furnace workers and to evaluate the effectiveness of control measures. The evaluation will include an analysis of data for the full period of the shift (8 hours or 12 hours), as well as the high risk periods (window periods).

3.3 METHODS

Twenty six healthy male furnace workers were included in the study and all were acclimatized to the high temperatures they work in. The study followed a factorial design and the workers were divided into groups. A risk assessment indicated that possible harmful conditions only existed during tapping and cleaning activities. This was also primarily when workers were present on the tap floor. General duties other than tapping and cleaning, were done under comfortable and cool environmental conditions. The WBGT and radiation heat results therefore, represents only the time periods for tapping and cleaning. Four workers worked at a furnace per shift. This amounts to a total of eight workers per shift for the two furnaces. Of the four workers, two performed tapping activities and two cleaning activities. The tappers were responsible for opening the hole in the furnace by first drilling it and then lancing it open with an iron rod through which oxygen were blown. The slag or iron flows through a launder into a ladle positioned underneath the launder. Cleaners then proceeded to clear the launders of slag or iron that was lying in the launder and have cooled down.

Two 8 hour shifts and two 12 hour shifts were included in the monitoring period. The four workers at a furnace were monitored on the same day and monitoring took place over a period of 7 days. All measurements were taken under normal working conditions.

The 26 workers included in the study were divided into homogenous groups, namely 8h Tappers (n=6), 8h Cleaners (n=5), 12h Tappers (n=7) and 12h Cleaners (n=8).

3.3.1 Hydration Status

3.3.1.1 Urine Specific Gravity (USG)

Urine specific gravity is dependent on the concentration of solutes in the urine sample and is used as an indication of the hydration status of a worker. Urine with a high osmolarity (i.e. higher concentration solutes), will result in a dark colour and a state of hypo hydration (decreased hydration levels) (Joubert and Bates, 2008). USG was measured by means of Combur Test® strips. USG from Combur strips was obtained by briefly inserting a test strip in urine and was followed by colorometric comparison with provided reference colours.

3.3.2 Core Temperature (CT)

3.3.2.1 Intra-abdominal core temperature

Continuous real-time core temperature was measured by means of a ingestible miniature sensor (HQ Inc. Wireless Sensing Systems and Design) that vibrates at a frequency relative to the temperature of the body tissues surrounding it. The sensor sends a harmless wireless signal to a recorder worn on the worker's belt. Any worker who did not comply with the contra-indications did not ingest the sensor. The core temperature was logged on the recorder every 20 seconds for the duration of the shift.

3.3.3 Heart rate (HR)

Each worker wore a POLAR® heart rate transmission strap. The ambulatory recorder used to log the core temperatures also logged heart rate, received from the POLAR® transmission strap, every 20 seconds. The transmission strap was worn for the duration of the shift.

3.3.4 Physiological Strain Index (PSI)

PSI was calculated according to Moron's (1998) formula, incorporating CT and HR in the following relationship:

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

where T_{ret} and HR_t are simultaneous measurements taken at any time. T_{re} and HR, which depict the regulatory systems, were assigned with the same weight by using a constant of 5. The scale works between 0 and 10 (5-6 being moderate) within the limits of $36.5 \leq T_{re} \leq 39.5^{\circ}C$ and $60 \leq HR \leq 180$ beats/min.

The PSI formula takes the baseline HR and CT of the person into consideration. A baseline value for HR and CT were taken for 30-40 minutes.

3.3.5 Heat stress (WBGT Index)

The environmental conditions on the tap floor were measured with a heat stress instrument (QUESTemp°34 Quest Technologies). Dry bulb-, wet bulb-, radiant temperature, WBGT index and relative humidity were derived from the heat stress instrument.

During tapping activities the heat stress instrument was positioned where the tappers rested (Figure 1). Tappers wore silver, reflective, semi-encapsulating protective clothing that included pants, a jacket, gloves, foot protection and head protection. One tapper lanced the opening of the furnace while the other stood on the side and replaced the lances when it became too short. When the hole was open and slag flowed through the launder both tappers stood on the side, in front of jet fans and took turns in clearing the launder of occlusions resulting from the cooling of slag. During these resting periods, tappers took off their head protection while sitting in front of the fan, approximately 7 m from the furnace. When the ladle (container beneath the launder) was filled, the hole was plugged. Due to the extreme temperatures of the slag (1750 °C) and iron (1450 °C) (Gous, 2004) it was impossible to place the instrument next to the launder where the tapper stood. A radiation ball (150 mm diameter) was placed 3 to 4 m from the launder to attempt to capture the immense radiation emitted from the hot molten metal.

After the slag has cooled in the launder cleaners would start to remove and clear it. During cleaning activities the heat stress instrument and radiation ball were placed next to the launder where the cleaners were working.

3.3.6 Ratings of perceived exertion (RPE)

Each worker completed a questionnaire to determine their psychological perception of the intensity of their work. They indicated their perceived exertion on Borg's 15-grade scale (Borg, 1982).

3.3.7 Ethical approval and informed consent

All protocols were approved by the Ethics Committee of the North-West University, NWU-0074-08-A1. Workers were informed verbally of the purpose, procedures, potential discomfort, duration and benefits of the study and also completed an informed consent form before commencement of the study.

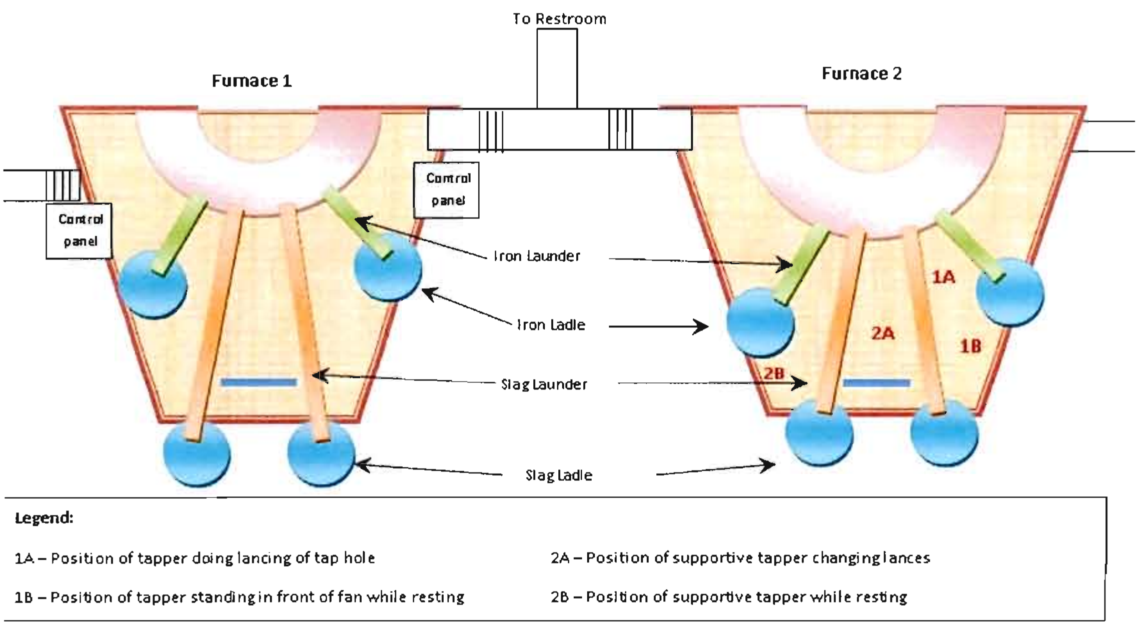


Figure 1: Position of tappers on the tap floor.

3.3.8 Data and Statistical analysis

Division was made between data used to calculate exposure for the full period of the shift and for high risk window periods.

Statistical analysis was done by using Statistica 8 (Statsoft Inc.) and Microsoft Excel (Microsoft Corporation).

Statistical analysis included basic statistics (mean, standard deviation, minimum and maximum values), as well as T-tests. Paired T-tests were performed on urine sample results at the beginning and again at the end of the shift in order to determine if there was a difference in hydration status. All differences were considered as statistically significant at a level of $p < 0.05$.

3.4 RESULTS

3.4.1 Anthropological and physiological data

Table 1: Mean anthropological and physiological data for the subjects

Group/Subject	Age	Height (cm)	Weight (kg)	BMI
8H CLEANERS Mean ± SD	28 ± 6	175 ± 5	80.0 ± 17.9	26.0 ± 5.4
8H TAPPERS Mean ± SD	35 ± 5	177 ± 6	85.7 ± 5.4	27.5 ± 2.0
12H CLEANERS Mean ± SD	30 ± 8	173 ± 6	78.7 ± 19.6	26.3 ± 5.3
12H TAPPERS Mean ± SD	32 ± 7	174 ± 7	73.1 ± 13.4	24.1 ± 4.3

SD Standard deviation

BMI Body mass index

3.4.2 Environmental measurements

3.4.2.1 Environmental temperatures

This study was conducted during mid spring and Table 2 depicts the temperatures of each day of measurement as obtained from the South African Weather Service. Temperatures averaged between 17.1 °C and 20.2 °C. The highest temperatures

(25.7 °C and 26.5 °C) were reached on day 1 and 2 of the 12h shift monitoring. Morning temperatures (from 07:00) ranged between 1.9 °C and 5.5 °C.

Table 2: Environmental temperatures outside the smelter building for each day of the study.

	8h Shifts				12h Shifts			
	Day 1	Day 2	Day 3	Day 4	Day 1	Day 2	Day 3	Day 4
Mean ± SD	18.0 ± 2.8	17.3 ± 2.3	20.2 ± 4.9	18.3 ± 5.5	21.7 ± 4.4	21.1 ± 4.5	17.1 ± 1.9	17.2 ± 3.3
Minimum	11.6	12.3	9.2	6.1	10.3	10.3	14.3	9.7
Maximum	20.0	19.1	24.7	22.6	25.7	26.5	19.7	20.6

All values given as °C

3.4.2.2 Environmental conditions on the tap floor

The environmental measurements represent only the periods of high risk exposure, that is tapping and cleaning periods. Data were recorded every minute and the mean for each tap was calculated. Mean values for all the taps were calculated for each group.

The average duration of each iron tap was approximately 40-50 minutes. Slag taps lasted for approximately 20-25 minutes. If however, a double slag tap was performed, the duration was approximately 20 minutes longer. The duration of cleaning activities depended on self pacing of the workers. Cleaning of slag launders depended on the temperature of slag remaining in the launder. When slag was at higher temperatures, cleaning times were usually shorter, since the slag would break into bigger pieces which could be more easily removed. Slag that had cooled down broke into smaller pieces and crumbled easily. Removal therefore took longer, but environmental temperatures were lower. The choice of method depended on the workers. Cleaning of iron launders were not done under high temperatures and did not entail hard manual labour, and it wasn't included in the study.

In order to determine the WBGT Index reference values to which the acquired results should be compared to, Table 1 of ISO 7243 (1989) was used to classify each group's level of metabolic rate. By taking the nature of work activities into consideration, tappers were classified as having moderate metabolic rates and cleaners high metabolic rates. The reference value for WBGT results, derived from ISO 7243 (1989) for acclimatized workers, is 26 for cleaners and 28 for tappers. No clothing adjustment factors (ACGIH, 2008) were applied to compensate for protective clothing. The woven overalls do not require any adjustments and no adjustments are available for encapsulating suits.

From Table 3, mean WBGT values of all the groups do not exceed these reference values, except for 12h cleaners who are marginally below this limit. Some of the maximum WBGT values recorded did exceed the limit during 12h shift tapping and cleaning activities, but for the 8h shifts this was only the case for 8h cleaning activities.

When considering radiation heat conditions, mean globe temperatures (150mm Globe) (Table 4) varied for the type of activity and shift. The importance of these measurements is justified by the presence of hot molten metal and therefore large amounts of radiation heat. Even though the WBGT readings rarely exceeded the limit, radiation heat has a great influence on the working conditions and comfort in the environment. Mean globe temperatures were found to be lower during iron tapping than slag tapping. This correlates with the fact that the temperature of slag is approximately 300 °C higher than the temperature of iron.

Whilst cleaners are performing their activities, they are in a bent position over the launder. They also wear less reflective and protective clothing than the tappers, and depending on how long they wait before commencing the cleaning, they are exposed to a high amount of radiation heat in close proximity.

At no stage during tapping was it possible to position the globe at the exact position of the tappers next to the launder due to the risk of damage to the instrument. As the opening of the furnace was lanced open temperatures increased gradually. As soon as the opening was plugged, temperatures started to decrease again. Maximum temperatures for iron taps were recorded between 51.1°C and 60.8°C and between 64.9°C and 70.3°C for slag taps (Table 4). It is important to note that the instrument was positioned closer to the source of heat during iron tapping. The results for slag and iron taps can therefore not be compared.

During the cleaning of slag launders average globe temperatures ranged between 42.5 °C and 69.0 °C. Maximum globe temperatures ranged between 48.4 °C and 85.6 °C.

Table 3: Heat stress results on the tap floor for cleaning, iron tapping and slag tapping.

Description	8h Shifts			12h Shifts		
	Cleaning	Iron Tapping	Slag Tapping	Cleaning	Iron Tapping	Slag Tapping
WBGT$_o$						
Mean ± SD	22.9 ± 2.9	19.9 ± .4	23.0 ± 2.6	25.9 ± 7.3	21.6 ± 2.7	23.2 ± 2.8
Minimum	19.8	18.0	18.1	18.3	17.8	17.1
Maximum	27.8	22.9	27.6	39.6	31.6	32.3
GLOBE TEMPERATURE (°C)						
Mean ± SD	30.2 ± 4.9	27.1 ± 3.1	32.9 ± 6.0	34.2 ± 9.7	28.5 ± 5.8	32.5 ± 6.4
Minimum	24.3	22.7	22.3	22.0	21.4	20.2
Maximum	40.8	33.6	46.0	54.4	52.4	53.6
WET BULB TEMPERATURE (°C)						
Mean ± SD	19.8 ± 1.3	17.2 ± 1.0	19.9 ± 1.7	23.3 ± 7.3	19.2 ± 1.7	20.2 ± 1.8
Minimum	17.9	15.9	16	17.1	16.7	16.2
Maximum	22.6	19.8	23.2	38.3	25.3	25.7
DRY BULB TEMPERATURE (°C)						
Mean ± SD	27.2 ± 2.3	24.2 ± 1.4	27.3 ± 2.9	28.5 ± 6.9	24.8 ± 4.1	26.7 ± 3.8
Minimum	23.4	21.9	21.4	20.0	18.7	17.6
Maximum	31.1	27.8	33.4	39.7	36.1	40.8

SD Standard Deviation

☐ Indicates a value above the reference value of the WBGT-Index (ISO 7243):

- WBGT ≥ 26 for high metabolic rates (Cleaners)
- WBGT ≥ 28 for moderate metabolic rates (Tappers)

During cleaning: Instrument was positioned approximately 2 meters from the slag launder.

During iron tapping: Instrument was positioned approximately 4-5 meters from the iron launder.

During slag tapping: Instrument was positioned approximately 7 meters from the slag launder.

3.4.3 Physiological indicators

Due to the difficulties experienced with data acquisition in the field, core temperatures taken with the thermometer, USG with the urinometer and body weight measurements were not included into the results since data proved to be unreliable. Other methods used to measure core temperature and hydration of workers provided reliable data and was included in the results.

Two different sets of graphs were drawn. The first (Figure 2, 4 and 6), to represents the mean parameter for the full duration of the shift, together with standard deviation and p-values between groups. The second (Figure 3, 5 and 7) represents the mean parameter during window periods, also with standard deviation and p-values. These window periods respresent the high risk exposures during the shift, namely the time period for cleaning and the time period for tapping.

Table 4: Radiation heat measured by the 150 mm Globe on the tap floor.

Description	8h Shifts			12h Shifts		
	Cleaning	Iron Tapping	Slag Tapping	Cleaning	Iron Tapping	Slag Tapping
Mean ± SD	69.0 ± 14.4	42.4 ± 16.0	47.5 ± 20.1	42.5 ± 7.3	40.6 ± 9.1	46.2 ± 16.1
Minimum	59.4	24.5	27.3	35.5	30.4	31.7
Maximum	85.6	60.8	70.3	48.4	51.1	64.9

All temperatures given in °C

SD: Standard deviation

During cleaning: Instrument was positioned approximately 2 meters from the slag launder.

During iron tapping: Instrument was positioned approximately 2-3 meters from the iron launder.

During slag tapping: Instrument was positioned approximately 4-6 meters from the slag launder.

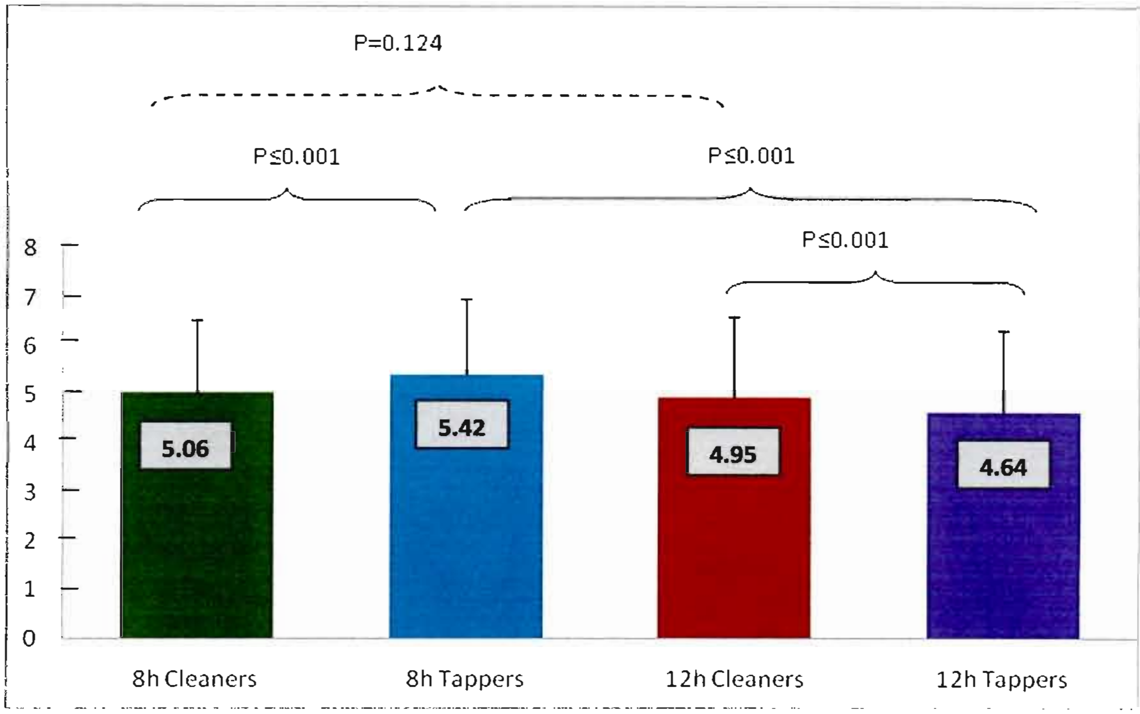


Figure 2: Mean PSI values for the 8h Cleaners, 8h Tappers, 12h Cleaners and 12h Tappers during a ***full shift***.

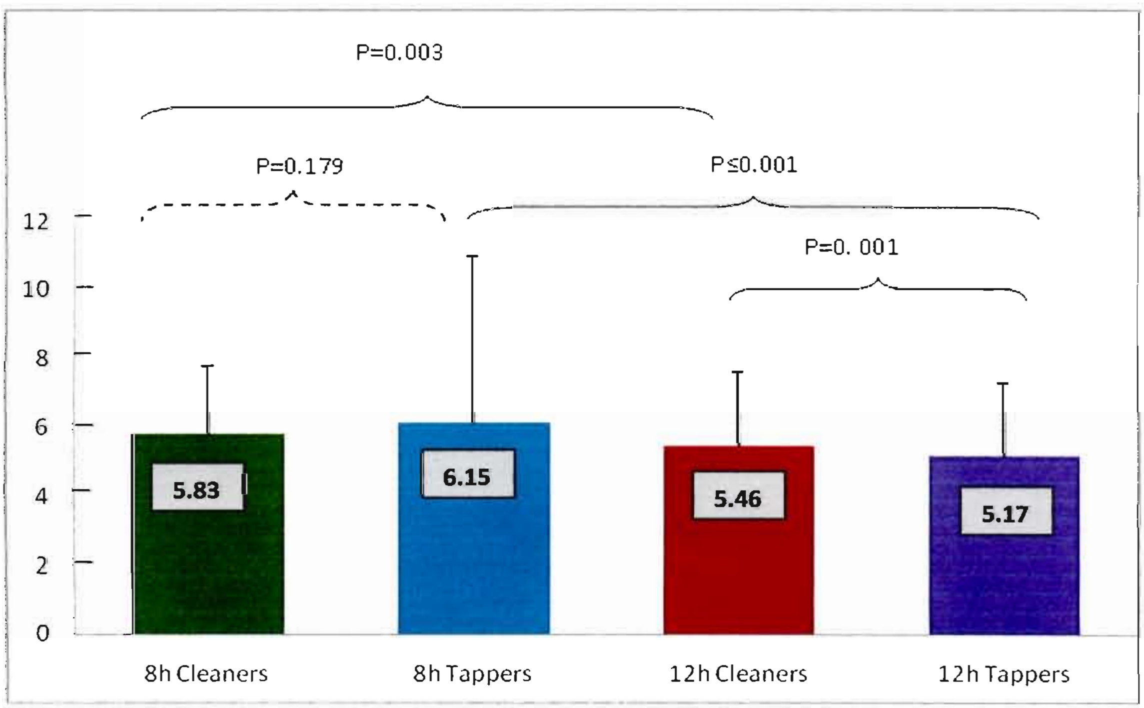


Figure 3: Mean PSI values for the 8h Cleaners, 8h Tappers, 12h Cleaners and 12h Tappers during ***window periods***.

Statistical significant difference between two indicated groups

No statistical significant difference between two indicated groups

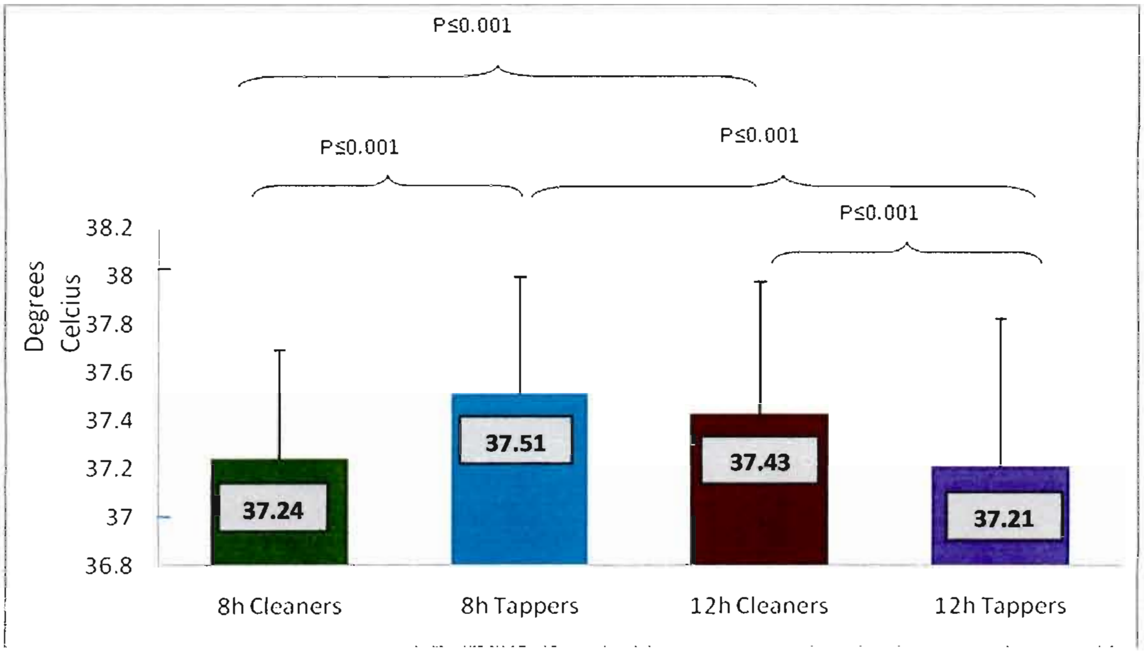


Figure 4: Mean CT for the 8h Cleaners, 8h Tappers, 12h Cleaners and 12h Tappers during the ***full shift***.

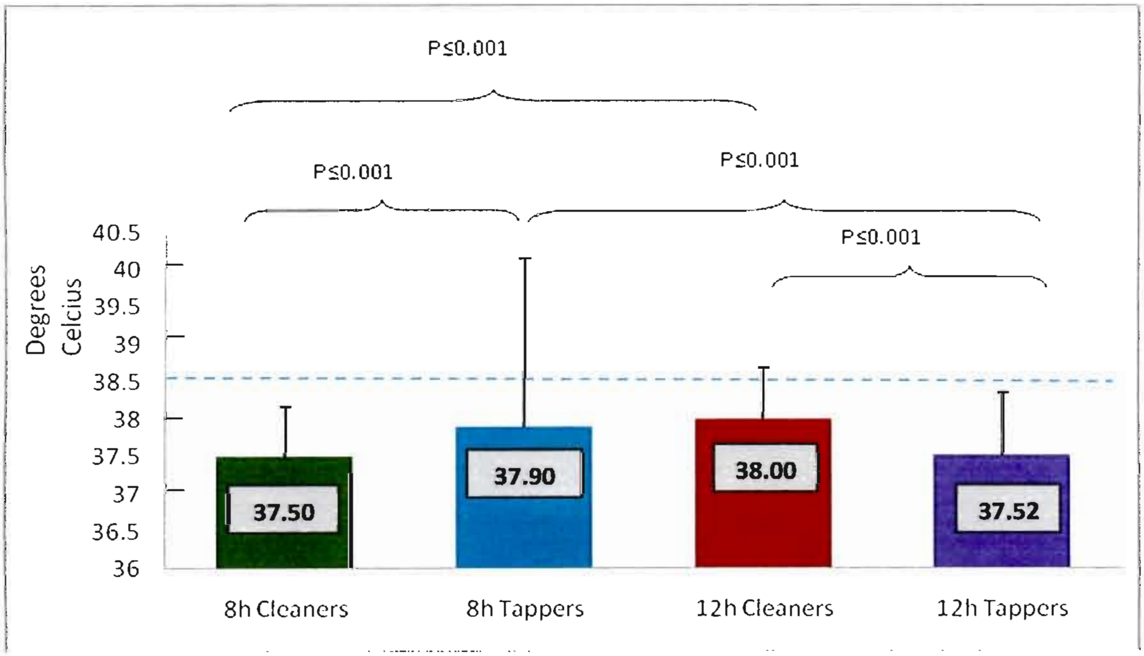


Figure 5: Mean CT values for the 8h Cleaners, 8h Tappers, 12h Cleaners and 12h Tappers during ***window periods***.

- - - - Core temperature limit for acclimatized workers according to ACGIH (2008)

Statistical significant difference between two indicated groups

No statistical significant difference between two indicated groups

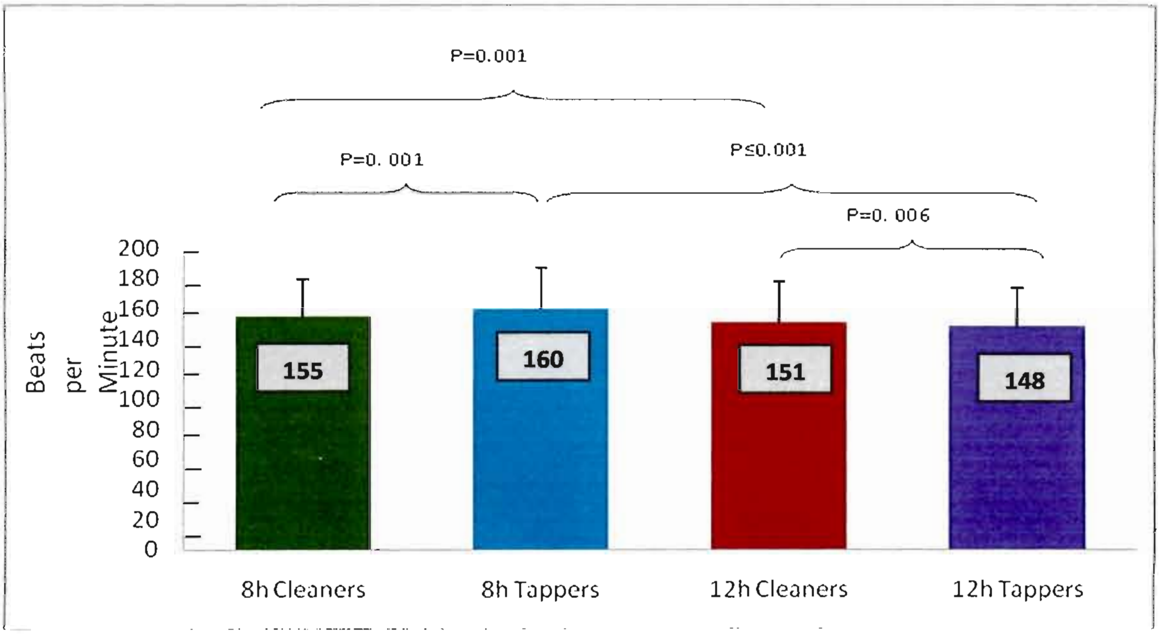
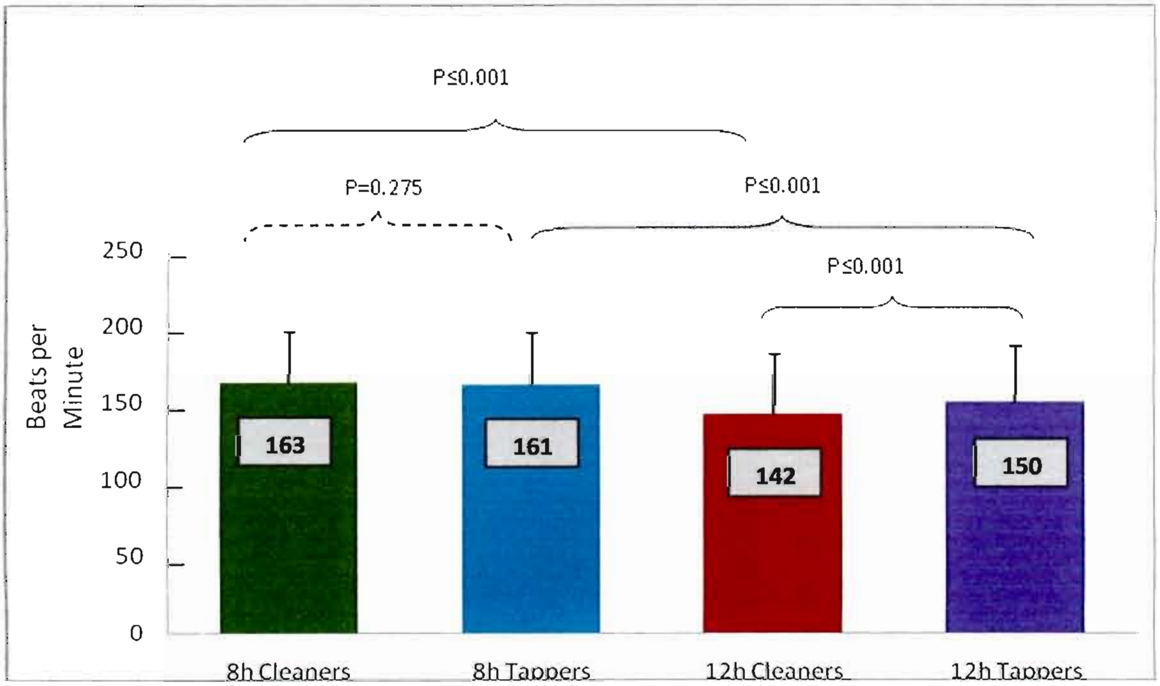


Figure 6: Mean HR for the 8h Cleaners, 8h Tappers, 12h Cleaners and 12h Tappers during the ***full shift***.



Statistical significant difference between two indicated groups

No statistical significant difference between two indicated groups

Figure 7: Mean HR for the 8h Cleaners, 8h Tappers, 12h Cleaners and 12h Tappers during the ***window period***.

For the calculation of full shift values, PSI, CT and HR data were averaged over a period of 2 minutes. Mean values, standard deviation and p-values were calculated with these 2 minute averages for the time period (either 8 hours or 12 hours) of the shift. Since the window periods of high risk exposure were a shorter period, mean values, standard deviation and p-values were calculated with data at 20 second intervals and not averaged for 2 minutes.

When comparing the graphs and results of the full shift period and window period, higher values, and therefore higher strain, were found during window periods for all three indicators, with the exception of heart rates of 12h cleaners being lower. This was to be expected since the window periods represent high risk exposures. Heart rates showed a slightly different pattern between groups than PSI and CT. Here the 8h Cleaners had the higher heart rates. No conclusive explanation can be given as reason for the differences.

Mean PSI values showed that during the full shift workers only experienced low (3-4) to moderate (5-6) strain and during window periods moderate (5-6) strain. When analysing individual data it was found that at some stages during the day there were workers who experienced very high strain. During window periods (Figure 3) high, to very high strain levels were reached. A comparison between the two shifts indicated that tappers experience significantly more strain during 8h shifts, whereas cleaners had higher PSI values during 12h shifts (Figure 2 and 3). No significant difference as ascertained between 8h and 12h Cleaners working a full shift. Figure 3 however shows that 8h Cleaners experience significantly higher strain than 12h Cleaners during window periods. No significant difference was found between 8h Cleaners and Tappers during window periods for PSI.

Figure 4 indicates that none of the mean core temperatures exceeded the limit of 38.5°C, as given for acclimatized workers (ACGIH, 2008). For the duration of the full shift, mean core temperatures ranged between 37.21°C and 37.51°C. Figure 4 also indicates that as with PSI, 8h Tappers had the highest core temperatures. 12h Cleaners had significantly higher core temperatures than 8h Cleaners and 12h Tappers.

Mean CT results during window periods also indicated that none of the groups exceeded the limit of 38.5°C, and these values were higher than mean values for the full shift.

A paired T-test showed that no significant statistical difference existed between USG values at the beginning and end of the shift (Table 5). 80% of workers were adequately hydrated [1.000 – 1.021 (Joubert and Bates, 2008)] at the beginning and end of the shift and the other 20% were hypo hydrated [1.022 – 1.026 (Joubert and Bates, 2008)]. Although 20% of workers showed a higher USG value at the end of the shift, they were not dehydrated. The rest of the workers did not show a change in their hydration status.

Table 5: Results of paired T-test performed on USG at the beginning of the shift and again at the end of the shift.

Job Category	Mean (g/ml)		Mean Difference	SD of Mean Difference	p-value
	Before shift	After shift			
8h Tappers	1.019	1.016	0.003	0.008	0.426
8h Cleaners	1.018	1.012	0.006	0.011	0.284
12h Tappers	1.021	1.022	-0.001	0.002	0.351
12h Cleaners	1.016	1.016	-0.001	0.003	0.604

The Ratings of Perceived Exertion (Borg, 1989) questionnaires indicated that tappers perceived their work activities as physically more challenging. 43% of cleaners rated their work as 'somewhat hard', 43% as 'hard' and 14% rated it as very hard. 50% of tappers rated their work as 'hard', while 30% rated it as 'very hard' and 20% as 'very very hard'. The workers rotate monthly between performing tapping and cleaning activities, and therefore it is possible to compare the two job categories.

3.5 DISCUSSION

Comparisons between 8h Cleaners, 8h Tappers, 12h Cleaners and 12h Tappers indicated various significant differences for the different physiological indicators. Division between average strain for subjects during the full shift and during window periods was made, and window periods consistently resulted in higher physiological strain values (except HR of 12h Cleaners). Even though the window periods resulted in higher strain, mean PSI values showed that workers experienced moderate strain during window periods as well as during their full shift, except for 8h Tappers who experience high strain during their tapping times. The results indicate that the subjects' high short term exposure had a great influence on the average amount of strain experienced during the day.

When analysing the data of individual subjects during window periods, there were periods when they experience high, to very high strain. These periods did not prevail for longer than 2 to 5 minutes though, and subjects recovered successfully after it. One subject from the group of 8h Tappers however, showed an average core temperature of 39 °C for a period of 20 minutes. Although he did not show any symptoms indicating a risk for heat related disorders, long term effects could be hazardous to his health. Long term effects could include kidney, liver, heart, digestive system, central nervous system and skin illnesses, but evidence of these conditions is unfortunately not conclusive (CCOHS, 2008). This also emphasises the inter-individual differences existing between workers. Monitoring of this specific worker should be continued closely.

In order to explain differences between groups, influencing factors were analyzed. Since the heat stress instruments were not placed in the same position during cleaning and tapping, a comparison cannot be made for environmental conditions. The source of heat, namely the furnace, generates heat at a constant rate and it was concluded that it would not cause large variations in temperatures. Other factors that could have had an influence on the temperature conditions on the tap floor include wind movement and temperatures outside the smelter building. With regards to air movement, wet bulb temperatures during 8h shifts ranged between 17.2 and 19.9°C. These values were greatly affected by the position of the jet fans on the tap floor.

Protective clothing differed for the cleaners and tappers. As mentioned, tappers wore reflective, semi-encapsulating gear over their heat resistant overalls. Tappers therefore had enhanced protection against radiation heat, but their ability to lose heat through evaporation was impaired because of the clothing. Cleaners wore the same reflective protection around their lower legs and were further attired with a balaclava and heat resistant overall. Cleaners were therefore protected less against radiation heat, but could lose heat more easily through sweat and evaporation.

Dehydration can decrease the tolerance of heat stress (ACGIH, 2008; Guyton and Hall, 2006; Willmore and Costill, 2004). As seen from Table 5, all of the workers were adequately hydrated during the period of the shift. 20% of the workers were mildly more dehydrated at the end of the shift. According to Joubert and Bates (2008), adequate hydration (1.000 – 1.021 g/ml, as is the case with 80% of the workers) poses a low risk to workers and no action is required. Workers who are hypo hydrated (20%), are exposed to a moderate risk and should drink 1L of water immediately. All of these workers worked 12 hour shifts. Workers in the 8 hour shift were all adequately hydrated.

Due to the nature of taking measurements in the field and accommodating subjects who have certain time constraint responsibilities, the use of the urinometer for measuring USG was found ineffective. Temperature correction, which needs to be taken into consideration made the practical execution thereof difficult. Use of Combur Test strips were more easily applied and provided more reliable results. Difficulty was also experienced with the use of weight loss as indication of dehydration. Subjects could not reliably keep tract of and report their fluid intake.

Anthropological data shows that subjects in the group for 8h Tappers had the highest average age and BMI values. They had an average age of 35 years, and average BMI of 27.5, which indicates that subjects in this group were overweight. According to ACGIH (2001), body fat is a good thermal insulator and conducts heat merely 36% as well as skin or muscle. Despite the disadvantages, the ACGIH (2001) also states that people who were chronically overweight have been found to perform just as well in hot environments as people with a lower BMI. This can be attributed to job experience and increasing physical fitness. They also state that age by itself may not be the most important criterion. Physical condition and debilitations generally associated with age are more significant.

The calculated mean core temperatures of all eight groups did not exceed the limit of 38.5°C as stated by the ACGIH (2008). As mentioned previously, except for 8h Tappers during window periods, the PSI index indicated that subjects experienced only moderate strain. These results reflect on the fact that all of the workers were extremely well acclimatized and aware of their rate of self pacing. They kept themselves fairly adequately hydrated and together with effective control measures, heat strain was limited.

Use of the miniature transponders instead of taking core temperatures with an oral thermometer resulted in very accurate measurements. The transponders were also relatively unaffected by environmental temperatures and provided continuous measurements of CT regardless of the activity performed in their daily routines.

A comparison may also be made between psychological and physiological experience of heat strain. RPE (according to Borg's Scale, 1989) indicated that overall, tappers rated their activities as more strenuous than cleaners' activities. Physiological data and comparisons do not give a conclusive answer as to which is harder, a lot of inter-individual changes existed. RPE should be compared with each individual's physiological data and not generalized for the whole group.

When analysing the different indices used in this study, as well as advantages and disadvantages thereof, the following was found: Although the WBGT index provides a good indication and guidance as to the environmental conditions, it was not possible to provide an accurate measurement thereof. If it was possible to place the instruments at the exact positions where tappers and cleaners were working results would have been different, but due to the risk of damage to the instruments it was not possible. Difficulties with placement of heat stress instruments, as well as the importance and significance of inter-individual differences in heat tolerance, makes the use of PSI and physiological indicators more effective. A shortcoming of the PSI, is that it works within certain limits, namely for $36.5 \leq T_{re} \leq 39.5^{o}C$ and $60 \leq HR \leq 180$ bpm (Moron, 1998). It was found that workers easily had core temperatures and heart rates outside of these limits and still did not show any signs of heat related disorders. This finding limits the application of the index.

3.6 CONCLUSION

This study indicated that furnace workers at an iron smelter experiences moderate to high heat strain while performing their work activities. It may also be concluded that when evaluating heat strain it is important to evaluate each individual's physiological indicators and not just general environmental conditions. A subject's strain can be limited by applying certain factors, namely being well acclimatized, keeping themselves adequately hydrated, pacing their work to rest ratios and keeping their own health of a high standard by keeping a healthy lifestyle. Taking into consideration that long term effects are still not conclusive, each individual should continuously be monitored closely to ensure their safety in the work environment.

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CHAPTER 4: CONCLUDING CHAPTER

4.1 Conclusion

This study made it possible to quantify the physiological strain experienced by furnace workers in the field, as well as the environmental conditions.

It indicated that furnace workers at an iron smelter experience moderate to high heat strain while performing their work activities. Measuring intra-abdominal core temperature for the duration of the shift, made it possible to quantify the workers' strain while they are wearing all of their protective equipment and doing their job activities, in the high temperatures. As a result, each worker's data could be studied and evaluated on its own, as well as in a group.

There were four extremely important factors that played a significant role in the amount of strain experienced, namely: acclimatization, self pacing of the worker, their ability to discern the amount of fluid intake essential, and effective control measures in the workplace. The subjects included in this study were all well acclimatised and aware of the rate at which they could perform their activities. Acclimatization helps to fine tune sweat reflexes resulting in an increase in the sweat production rate as well as lower electrolyte concentrations. It also improves productivity and safety by providing more stable and better regulated blood pressure (ACGIH, 2001). The workers were able to balance the ratio of work against rest effectively. They were also provided with energy drinks containing electrolytes to replenish their fluid losses and, as demonstrated by USG test results, they were adequately hydrated.

None of the workers showed any symptoms of heat related disorders, even though some had very high core temperatures and heart rates recorded. Unfortunately, long term effects of exposure to heat and radiation heat are non-conclusive, and therefore the fact that workers could acutely cope with core temperatures exceeding the limit of 38.5 °C does not mean that it is not hazardous to their health in the long run.

Taking measurements in an uncontrolled environment such as the work place presents many challenges, e.g. it was not possible to place the heat stress instruments at the exact position where tappers stood due to the risk of damage to the instruments and it being in the way of the workers. The $WBGT_0$ values as well as radiation heat were therefore measured to be lower than the actual values experienced by workers. This makes the index to measure physiological indicators more accurate and effective.

It is important to choose the method of measurement carefully and to consider the environment of interest. During this study it was found that the use of a urinometer for USG does not provide reliable data. It was not possible for all of the subjects to provide their sample at the same time, and it was not always known what time period passed before USG could be determined. Temperature corrections were completed with difficulty and results were not accurate.

The same difficulties were experienced with the method of measuring difference in weight loss. Subjects were provided with a fluid container, and since they had different responsibilities at different periods of time, they were asked to keep tract of the amount of times they filled their container. Not all of the workers were able to keep reliable tract of their fluid intake and this makes the calculation of difference in body weight loss unreliable for use in the field.

This study indicated that when evaluating heat strain it is important to evaluate each individual's physiological indicators and not just general environmental conditions. Inter-individual differences are significant, and a person's heat tolerance will depend on personal characteristics as well a controlled environment. With the correct control measures in place it is possible to limit the amount of strain experienced by workers, but is not possible without the co-operation of the worker.

A subject's strain may be limited by applying certain preventative factors. This constitutes being well acclimatized, keeping adequately hydrated, pacing the work to rest ratios and keeping their own health at a high standard by keeping a healthy lifestyle. Subjects with a higher BMI showed a decrease in heat tolerance. Taking into consideration that long term effects are still not conclusive, each individual should continuously be monitored closely to ensure their safety in the work environment.

4.2 Recommendations

As mentioned in Chapter 1, due to the lack of South African standard for heat strain, recommendations were based on the ACGIH as well as recommendations by NIOSH.

4.2.1 Recommendations for further studies:

- Repeating of physiological parameter measurements of an individual.
- Conducting a similar study during mid summer in order to investigate the influence of ambient temperatures on the temperatures of the tap floor.
- Conducting a study to accurately determine the long term effects of heat exposure on physiological functions and organs.

4.2.2 Recommendations for limiting heat strain:

4.2.2.1 Evaluating heat stress and strain (ACGIH, 2008)

In order to ensure the safety of workers in hot environments, the ACGIH (2008) presents a decision process (Figure 8) that should be started under any of the following conditions:

1) A qualitative assessment reveals the possibility of heat stress.
2) Workers are reporting discomfort due to heat stress.
3) Professional judgement indicates heat stress conditions.

If any of the above conditions prevail, instigate the process by determining if clothing adjustments factors are available. Evaporation through sweat is the predominant heat removal mechanism, and clothing that impair this mechanism could cause strain to the worker. The WBGT-based index was developed for traditional work clothing of long-sleeved shirts and pants. The ACGIH (2008) provides clothing adjustment factors for other types of working gear. If clothing worn by workers is not included for in the adjustment factors, start performing physiological heat strain monitoring. If clothing adjustment factors are available continue to the next branch of Figure 8.

In order to determine the degree of heat exposure, the work patterns and demands needs to be taken into consideration. If work and rest phases takes place over differing locations, then a time-weighted average (TWA) WBGT should be compared to Table 2 (Screening Criteria for TLV® and Action limit for Heat Stress Exposure) of the ACGIH (2008). This table poses to keep most workers' body core temperature under 38°C by decreasing the criteria values as metabolic rate increases. If results are found to be above the Action limit but below the TLV® general controls should be implemented. General controls include the following:

- Providing verbal and written instructions, annual training programs and other information on heat stress and strain. Training should include possible disadvantages of heat strain and also steps that the worker can take to monitor and decrease strain.
- Encourage drinking small volumes (±1 cup) of cool palatable water at least every 20 minutes.
- Permit self-limitation of exposure and encourage workers to look for signs and symptoms of heat strain in their co-workers.
- Monitor workers taking medications that may compromise normal cardiovascular, blood pressure, body temperature regulation, and renal or sweat gland functions, and inform them of the consequences. Include people who abuse or are recovering from the abuse of alcohol or other intoxicants.
- Encourage workers to follow a healthy life-style, ideal body weight and electrolyte balance.
- Consider making use of preplacement medical screening to identify those susceptible to systemic heat injury.
- Monitor the conditions of heat stress and reports of heat-related disorders.

If the screening criteria are exceeded, the next step in the process of decision making includes a detailed analysis. More information on exposures is needed for this step. If data is not available, physiological monitoring needs to be done to assess the degree of heat strain. If data is available for a detailed analysis, two questions may be posed. Was the Action Limited exceeded? And was the TLV® exceeded? As illustrated by figure 8, if the action limit was not exceeded, a low risk to heat strain is subsistent. If the TLV® was exceeded, physiological monitoring needs to be done. Otherwise, general controls needs to be implemented and maintained.

As found in the conducted study (Chapter 3), ACGIH (2008) also states that the risk and severity of excessive heat strain will vary widely among people, even under identical heat stress conditions. If physiological monitoring proved acceptable heat strain levels, general controls still need to be implemented. Excessive heat strain would need the implementation of job-specific controls. Job specific controls include the following:

- Engineering controls: Attempt to reduce the metabolic rate, provide general air movement, reduce process heat and water vapour release, and shield radiant heat sources, etc.
- Administrative controls: Set acceptable exposure times, allow sufficient recovery, and limit physiological strain.
- Personal protection: Needs to be acceptable and effective for the specific work practices and conditions at the location.

The most important objective with regards to heat stress management is the prevention of heat stroke. Good heat stress management cannot transpire without the cooperation of supervision and workers. Some of the most important factors required for the prevention of heat strain include fluid replacement, self-pacing, health status monitoring, maintenance of a healthy life-style and acclimatization.

4.2.2.2 Recommended controls specific for furnace workers:

Engineering controls

- Improve the insulation on the furnace wall – this may improve the temperature of the surrounding area.
- Ensure windows or doors are opened to ensure heat waves ventilating through.
- Provide airflow in the hot environment, i.e. fans and blowers. Ensuring that fans are moveable/portable will allow workers to position it according to their working position (NIOSH, 2009).

- Install shielding against radiation heat, especially shields positioned closer to the furnace and in front of the tapper.

Administrative controls

- Providing a cool rest area with cool palatable water. Additional electrolytes and replenishment drinks should be provided (NIOSH, 2009). Workers should be encouraged to drink at least a cup of fluid every 20 minutes (ACGIH, 2008).
- Provide a guide as to sufficient work-rest cycles (NIOSH, 2009). Each worker can then use the guide and adapt it according to their own experience of fatigue.

Personal protective equipment

- Protective clothing against radiation heat is crucial, especially to tappers who work with the hot molten metal as it leaves the furnace.
- Protective clothing should fit each individual well, in order to make handling of instrumentation and performing activities safe.
- Even though the slag is cooled down when cleaners are working on the launders, they still need clothing to protect their face, eyes and body. The heat resistant overalls, balaclavas, extra protection around the lower legs and work boots and shaded goggles offered effective protection to the workers in the study.

Since the overall health and well-being of an individual plays such an important role in their ability to tolerate heat, a company might consider the following as motivation and encouragement to workers for improving their health:

- Providing a fitness facility for workers where they can excercise together. Having a work out partner will help with motivation and commitment.
- Establishing sports teams and organising monthly sport and wellness days where teams compete against each other.
- Launching a competition for the biggest improvement of health or certain aspects thereof, for instance measuring muscle ratio as baseline and then again after a certain period. A reward may be provided for the winner.

All of the objectives were achieved with the execution of the study. Furnace workers were evaluated based on physiological and environmental monitoring of the full shift and an analysis of the high risk window periods was included. Physiological monitoring included continuous CT and HR, and the calculation of PSI based on the CT and HR. Hydration levels before and after the shift was determined by means of USG. Environmental monitoring was done with more difficulty but included WBGT measurements and radiation heat. Workers rated their physiological strain psychologically by means of the RPE questionnaire and recommendations on control measures were provided in this chapter.

The hypothesis that furnace workers are exposed to a high amount of heat strain which could lead to negative physiological effects and health risks can be partially accepted. There are times during high risk window periods where workers exceeded their physiological limits, but on average for the day they only experienced moderate strain. It was therefore also concluded that monitoring of heat strain can't only be expressed as an 8h average, but analysing the high risk periods separately is important.

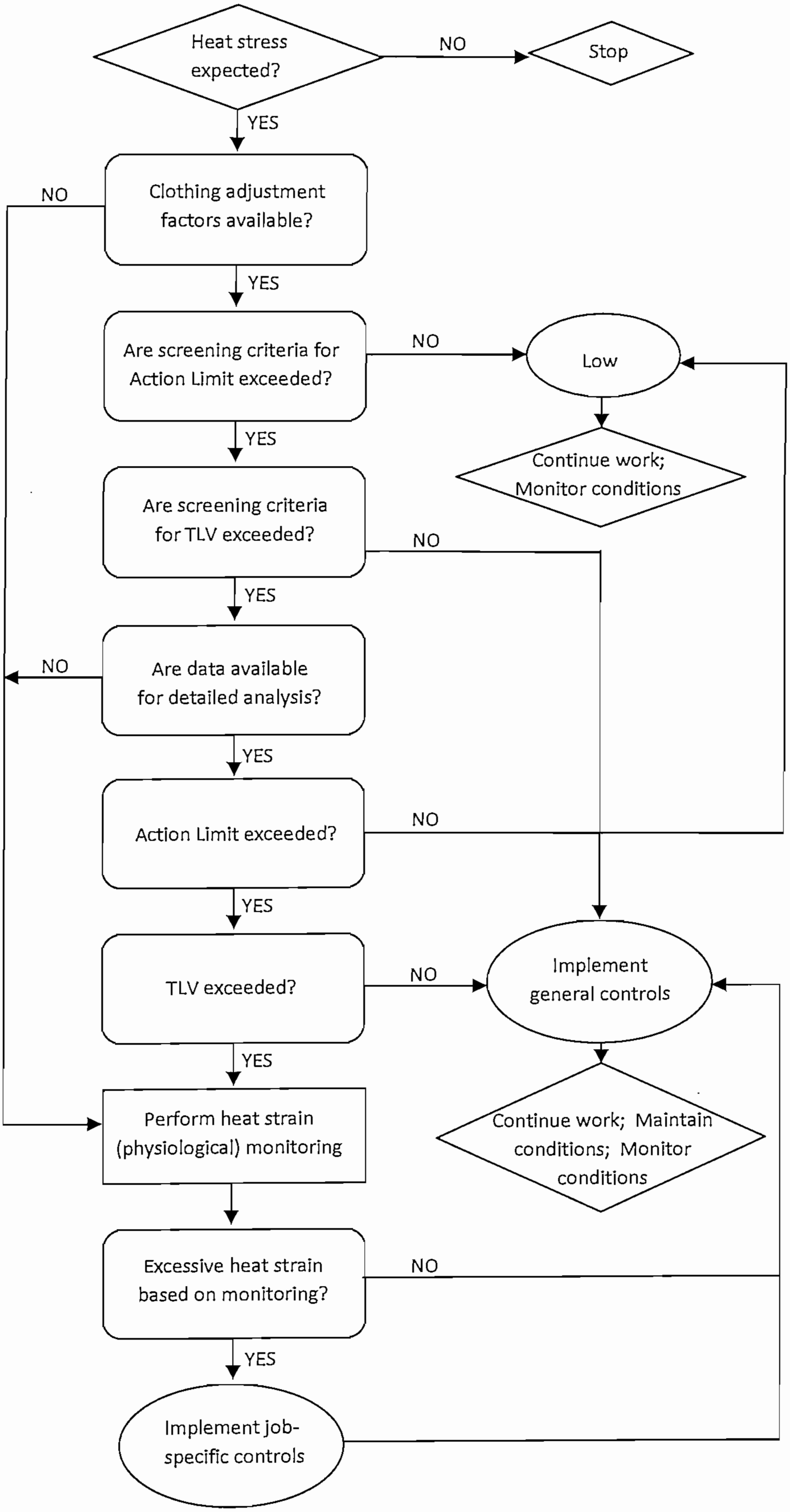

Figure 8: Evaluating heat stress and strain (ACGIH, 2008).

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CHAPTER 5: APPENDIX

The Ratings of Perceived Exertion Questionnaire /

The Vraelys vir die bepaling van Ervaarde Inspanning

(G.A.V. Borg, 1982)

Please fill in the following questions and make an X in the block in line with the value that you would rate the amount of exertion you experience while performing your daily working activities. / *Vul asseblief die volgende vrae in en maak 'n X in die blokkie regoor die waarde wat u sal aandui as die hoeveelheid inspanning wat u ervaar tydens u daaglikse werksaktiwiteite.*

1. Name and Surname / *Naam en Van*:

____

2. Job Category, namely Tapper or Cleaner / *Werks kategorie, naamlik Tapper of Skoonmaker:*

____

3. The 15-grade Scale for Ratings of Perceived Exertion / *Die 15-graad Skaal vir Bepaling van Ervaarde Inspanning (Borg, 1982):*

6	
7 - Very, very light / *Baie, baie lig*	
8	
9 - Very light / *Baie lig*	
10	
11 - Fairly light / *Redelik lig*	
12	
13 - Somewhat hard / *Ietwat moeilik*	
14	
15 - Hard / *Moeilik*	
16	
17 - Very hard / *Baie moeilik*	
18	
19 – Very, very hard / *Baie baie moeilik*	
20	