Mine Health and Safety Council

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Final Report

The relationship between physiological strain and physical work requirements in underground mines

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Executive summary

This study was conducted to expand the current information base of the relationship between physiological strain experienced by male and female mineworkers and physical work requirements during underground mining activities.

The programme of work was divided into four phases:

- A review of current information on the physical work requirements and the workloads/inherent physical job requirements/metabolic rates associated with underground occupations in thin tabular reef type mining at gold and platinum mines in order to identify ‘high risk’ occupations in terms of physical work intensity;
- The obtaining of ethics clearance from a human research ethics committee for planned research activities that will involve mineworkers;
- Field-based research *in situ* to assess the physiological strain experienced by male and female mineworkers in these ‘high risk’ occupations during work in extreme underground environmental conditions; and
- The formulation and theoretical evaluation of a holistic approach to manage excessive levels of physiological strain and make workloads compatible with the physical capacities of workers.

The first two phases of the work were completed within the proposed time frame. Great difficulties were, however, experienced in obtaining volunteers to participate in the third phase of the project, especially in the platinum sector. This phase of the project was aimed at assessing the physiological strain experienced by mineworkers in ‘high risk’ occupations in terms of physical work during their routine work underground at a gold and at a platinum mine, respectively.

The labour unrest at platinum mines around the country has had a negative effect on attempts to find a project mine to assist with the project. As a result of this unforeseen circumstance the planned date for completion of the third phase in the platinum sector was initially extended. Later, however, it was decided by the Safety in Mines Research Advisory Committee to terminate this phase of the project in view of the fact that no platinum mine was in a position to assist. The problem of recruiting mineworkers as volunteers for the project was a setback for the project.

Results obtained at the gold mine indicate that the levels of physiological strain exhibited by the male and female mineworkers while performing their routine duties underground were not excessive. Taking into account the physical nature of the tasks associated with the occupations assessed, coupled with the high thermal conditions and exposure to these conditions, one would have expected higher heart rates and body core temperatures and a greater percentage of the shift to be spent at moderate to high levels of physiological strain.

However, it appears that self-pacing has resulted in the relatively light to moderate levels of physiological strain observed. In a self-paced context, this ‘reduction in work rate’ is in line with the safe work practices associated with heat stress management.

The management of physiological strain caused by work-related factors should preferably be based on ergonomics principles. In this regard two control strategies are available: engineering controls and work practice controls. Engineering controls are controls that physically change (re-design) the workplace, tools, equipment and tasks in a way that they meet the capabilities of mineworkers, females as well as males. Work practice controls involve procedures and methods for adjusting work to avoid excessive physiological strain, such as self-pacing, the prevention of dehydration and the adherence to applicable heat stress limits.

Good ergonomic design of workplaces and tasks should be the primary strategy for preventing excessive physiological strain. However, when technical and physical constraints in the mining environment hinder the implementation of this strategy, the selection of workers on the basis of physical abilities could become part of a comprehensive plan for reducing excessive levels of physiological strain associated with mining tasks. Under these circumstances it is necessary to maximise the fit between the person and the work environment in the interest of health and safety.

The major limitation of the current study is the relatively small sample size and its composition, and that mineworkers from a platinum mine did not participate in the study as originally planned. In order to broaden the knowledge base of the physiological strain experienced by male and female mineworkers involved in thin tabular reef type mining, it is recommended that workers from a 'hot platinum mine (wet-bulb temeperatures ranging between 27.5ºC and 32.5ºC wet-bulb, with dry-bulb temperatures not exceeding 37.0ºC) also be studied when the industrial relations' climate in the platinum sector has normalised and a suitable project mine has been identified.

Acknowledgement

The assistance of the management, union representatives and mineworkers of the project mine at which fieldwork to assess physiological strain was conducted is acknowledged.

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1 Background

Reducing occupational injuries and ill health is a strategic objective of all the stakeholders in the South African mining industry. In order to achieve this objective it is necessary to provide the safest and healthiest working environment possible for all mineworkers, males as well as females.

To create an optimal work environment it is of cardinal importance to determine what is actually happening in the miners' work environment, i.e. to ask the question: what levels of physical strain are mineworkers experiencing while performing their tasks?

Most of the information on the metabolic rates of mineworkers involved in thin tabular reef-type mining in hard rock mines in South Africa is based on research conducted during the 1960s and 1970s and is rather dated. Current information on the physiological strain experienced by mineworkers involved in thin tabular reef type mining in hard rock mines is based on the physiological responses of mineworkers during pilot studies (Cowen and Schutte, 2009; Schutte and Formanowicz, 2010). Recent international studies dealing with the physiological demands of miners were performed in Canadian mechanised mines (Kenney et al., 2012) or coal mines in India (Saha et al., 2008) and Germany (Kalkowsky and Kampmann, 2006). The results of these studies were obtained in mines that use mining methods which differ from the thin tabular reef type mining in hard rock mines in South Africa and are therefore not directly applicable.

With the recent changes in the demographics of the workforce in South African mining that have resulted from the milestone set for the employment of female mineworkers (Department of Minerals and Energy, 2004), a need exists to establish the role of gender in the physiological strain experienced by miners during typical mining activities. The majority of the studies to determine the physiological demands associated with mining referred to in the previous paragraph have focused on a male workforce and limited information is available on female mineworkers. In view of their smaller physical work capacity (Wasserman, 1999), physical strength (McArdle et al., 2001) and lower heat tolerance (Schutte et al., 2002), female mineworkers may experience undue physiological strain when performing prolonged and strenuous physically demanding tasks as is the case in mining.

In order to expand the current information base on the physiological strain experienced by mineworkers during thin tabular reef type mining in hard rock mines in South Africa, the current study has been undertaken to determine the relationship between physiological strain and physical work requirements, taking into account the physical environment, occupation, work/rest cycles and gender.

The intention was to focus initially on the gold and platinum mining sectors in view of their difficult working conditions and physically demanding occupations. On successful completion of the research in these sectors the need to extend the research to other mining sectors could be decided by the Mine Health and Safety Council.

Quantifying the physiological strain mineworkers experience while performing various tasks would assist with the identification of underground occupations associated with high levels of physiological strain and the development of strategies to prevent or mitigate excessive physiological strain associated with mining activities.

The programme of work in the project was divided into four phases:

- A review of current information on the physical work requirements and the workloads/inherent physical job requirements/metabolic rates associated with underground occupations in thin tabular reef type mining in order to identify 'high risk' occupations in terms of physical work intensity (Enabling Output 1);
- The obtaining of ethics clearance from a human research ethics committee for planned research activities that will involve mineworkers (Enabling Output 2);
- Field-based research *in situ* to assess the physiological strain experienced by male and female mineworkers in these 'high risk' occupations during work in extreme underground environmental conditions (Enabling Output 3); and
- The formulation and theoretical evaluation of a holistic approach to manage excessive levels of physiological strain and make workloads compatible with the physical capacities of workers (Enabling Output 4).

The current report deals with the results obtained during the various phases of the project.

2 Enabling Output 1: Review of current information on the physical work requirements and the workloads, inherent physical job requirements and metabolic rates associated with underground occupations

2.1 Methodology

The following methodology was adopted to achieve Enabling Output 1:

- A review of existing information on the physical work requirements and the workloads associated with underground occupations in thin tabular reef type mining at gold and platinum mines in the South African mining industry;
- A workshop involving ergonomists, occupational hygienists and occupational therapists (all with experience in the assessment of physical workloads and functional job analyses) to discuss results of the review and to identify physical and ergonomics-related hazards in mining which impact on the ability to perform physical work;
- Construction of a matrix of the workloads, inherent physical job factors and metabolic rates associated with underground occupations; and
- Compilation of a list of ‘high risk’ occupations (in terms of physical work intensity and extreme environmental conditions) to be studied in detail at a gold and a platinum mine as part of Enabling Output 3.

In order to obtain information on the physical work requirements and metabolic rates associated with occupations in thin tabular reef type mining in South African gold and platinum mines, research reports and publications dealing specifically with this type of mining from the early 1960s up to 2011 were reviewed. Research reports that deal with the above topics were sourced from the Council for Scientific and Industrial Research (CSIR). In addition the following research engines were used to obtain information on thin tabular reef type mining in South Africa: Science Direct, Dialog, Ebso Discovery Service and the CSIR Research Space.

The results of functional job analyses performed on underground occupations at gold and platinum mines by staff of the Rehabilitation and Functional Assessment (RFA) Centre of Anglogold Ashanti were also incorporated in this section of the report. Their data was derived by means of direct observations.

2.2 Results and discussion

2.2.1 Literature review

The review deals with information on the metabolic rates and physiological strain associated with occupations in thin tabular reef type mining in South African gold and platinum mines.

2.2.1.1 Metabolic rates of mining tasks

In any environment potentially conducive to the development of human heat stress, a thorough understanding of the metabolic demands of tasks and activities is of fundamental importance in the assessment of heat stroke risk. During the development phases of heat acclimatisation and worker selection procedures to prevent heat disorders in the South African mining industry the physical demands of underground mining tasks associated with thin tabular reef type mining in gold mines have been the subject of considerable research (Morrison et al., 1968; van Graan et al., 1970; Johannes et al., 1975; van Rensburg et al., 1981). In these studies the focus was placed on energy expenditure associated with specific mining tasks based on the measurement of oxygen consumption. Although the measurement of oxygen consumption during physical activities gives an indirect estimation of metabolic rate (McArdle et al., 2001), it has certain limitations. Besides the fact that sampling instrumentation causes some discomfort and often impedes the execution of tasks, assessments can only be made over relatively short periods of approximately 15 minutes with workers being kept under surveillance (van Rensburg et al., 1991). Despite the aforementioned limitations the results obtained nevertheless provided useful information on the metabolic rates associated with mining tasks as summarised in Table 1 (Stewart, 1982).

Table 1: Classification of mining tasks according to metabolic heat production rates (Stewart, 1982)

Light work (less than 115 W/m²)	Moderate work (up to 180 W/m²)	Hard work (up to 240 W/m²)
Winch operation Sweeping Drill assistant duties Walking Drain cleaning	Building stone walls Operating box holes Drilling Barring Building matt packs Team leader duties	Tramming Shovelling Timber transport in stopes

A study conducted by van Rensburg and his co-workers in 1991 provides comprehensive information on the full-shift metabolic rates associated with conventional and mechanised mining occupations in gold mines. In this study metabolic rates were calculated from heart rate recordings of mineworkers in various occupations collected over a full shift. This methodology, described in ISO 8996:2004 (International Organization for Standardization), enjoys international recognition and permits taking into account the duration, intensity and frequency of peak metabolic rates as well as periods where no work is performed, or when work of low intensity is performed. Metabolic rates obtained in the study by van Rensburg and his co-workers (1991) are, on average, of a moderately high intensity (>130 W/m² to 180 W/m²). Hard work (metabolic rate 181 W/m² to 240 W/m²) is performed and is primarily associated with occupations directly involved with production. Very hard work (metabolic rate > 240 W/m²) is generally of short duration and appears to be the exception rather than the rule. The metabolic rates associated with conventional and mechanised occupations in the study are given in Table 2 and Table 3, respectively.

Table 2: Metabolic rates over a full working shift for conventional mining occupations at a gold mine (van Rensburg et al., 1991)

Occupation	Metabolic rate (W/m²)		
	Mean	Minimum	Maximum
Mine overseer	135.6	107.4	175.5
Shift boss (day shift)	148.1	123.0	185.5
Shift boss (night shift)	141.4	88.7	197.7
Equipper	136.9	124.0	151.3
Cleaner	146.8	123.1	179.5
Stoper	160.0	108.1	244.1
Developer	144.5	113.0	175.6
Team leader	157.9	106.8	260.9
Miner’s assistant	164.0	121.4	292.8
Winch driver	170.3	118.9	218.0
Loader driver	170.1	127.1	226.6
Equipping team	152.6	116.4	197.3
Cleaning team (night shift)	164.1	126.5	233.3
Stope team	163.9	114.5	297.3
Development team worker	163.3	131.8	227.3
Driller	176.1	120.0	287.3
Drill assistant	178.0	106.7	275.8
Pipes and tracts team worker	155.8	106.6	214.4
Vamping team	147.6	110.9	177.2
Loco crew	145.0	117.3	169.1
Electrician	129.2	112.7	152.3
Electrician aid	139.0	122.2	165.1

Table 3: Metabolic rates over a full working shift for mechanised mining occupations at a gold mine (van Rensburg et al., 1991)

Occupation	Metabolic rate (W/m²)		
	Mean	**Minimum**	**Maximum**
Shift boss	139.2	91.3	229.8
Miner	136.8	108.5	160.0
Roofbolt operator	153.1	94.7	223.9
Utility vehicle operator	134.8	101.2	212.0
Load haul dump (LHD) operator	134.4	98.1	214.0
Dump truck operator	139.1	100.2	194.7
Drill rig operator	166.6	95.2	219.2
Scaler operator	158.1	115.7	337.8
Pipes, tracks, ventilation (PTV) crew	155.9	116.5	230.9
Sampler	141.8	102.3	197.0
Miner's assistant	164.9	118.1	227.7
Electrician	152.6	112.8	217.3
Driller	175.9	128.3	239.5

2.2.1.2 Physiological strain associated with mining tasks

Two reports dealing with the physiological strain associated with thin tabular reef type mining in South Africa have been published to date. One report was of a pilot study conducted at a gold mine, which used 30 male mineworkers working at environmental temperatures ranging from 24.0°C to 31°C wet-bulb and with dry-bulb temperatures ranging from 26.5°C to 34.5°C (Cowen and Schutte, 2008). The other report also detailed a pilot study conducted at a platinum mine. This study used 11 male and eight female mineworkers working at environmental temperatures of between 19.0°C and 27.0°C wet-bulb, with dry-bulb temperatures ranging between 22.0°C and 29.0°C (Schutte and Formanowicz, 2010).

The objective of the pilot study at the gold mine (Cowen and Schutte, 2008) was to evaluate the CorTemp™ Physiological Monitoring System and the physiological strain index (PSI) developed by Moran and co-workers (1998) in terms of usefulness within the context of the mining industry. The results of the pilot study confirmed the usability and reliability of the CorTemp™ Physiological Monitoring System within the harsh environment of a deep underground mine and also confirmed the results of previous investigations using the PSI during intermittent, work-rest, physical activity exercise in the heat (Gotshall et al., 2001).

The occupations studied at the gold mine (Cowen and Schutte, 2008) included supervisors (mine overseers, shift overseers and team leaders), general mining team members, winch drivers and rock drill operators. The average working heart rate for the various occupations at the gold mine ranged from 88 to 96 beats per minute, while the mean body core temperature for the various occupations was between 37.2°C and 37.9°C. The levels of physiological strain measured were not excessive as workers were acclimatised to the work environments and workloads, and self-pacing enabled the mineworkers to sustain their average strain within a low range. The percentage of total shift time spent at low physiological strain levels was 91.6% for supervisors, 94.3% for winch drivers, 88.7% for mining team members and 98.6% for drillers. The high percentage of time spent at low physiological strain levels by drillers was an unexpected finding but was attributed to the fact that a number of the drillers sampled did not actually drill on the assessment days and hence a true reflection of the situation was not achieved.

Information on the physiological strain experienced by male and female mineworkers at a platinum mine during their routine underground work in cool areas (wet-bulb temperature < 27.5°C) is contained in a report by Schutte and Formanowicz (2010). In this study the physiological responses (heart rates, core body temperatures and PSI values) of a group of 19 mineworkers (eight females and 11 males) working day shift were compared. The following underground occupations were included in the sample: blasting assistant (one female), Cheesa – stoping (two males), diesel mechanic assistant (one male), loco driver (three females; one male), miner's assistant (one male), PTV team members (two females), scraper winch operator (one female; two males), stope timber (one female), store bay issue assistant (one male), surveyor (one male) and two male team supervisors.

Results of the abovementioned study indicate that females assessed experienced significantly more physiological strain than males when performing mining tasks. Sixty per cent of the male mineworkers experienced 'light' cardiovascular strain while performing mining activities compared to the 17.8% of female mineworkers. Approximately 49% of female mineworkers exceeded the heart rate limit above which cumulative fatigue is likely to ensue compared to the 13.5% of their male counterparts. Core body temperatures ranged from 35.8ºC to 39.3ºC and from 35.6ºC to 38.3ºC for females and males, respectively. Although the mean core body temperatures for both groups are acceptable in general, the maximum core body temperature recorded by one of the female mineworkers was of concern, especially since the thermal conditions were below 27.5ºC wet-bulb and not considered to be hot.

As far as the combined strain on the thermoregulatory and cardiovascular systems as reflected by the PSI is concerned, 21.2% of the PSI values of the female mineworkers fell within the moderate strain category and 2.6% within the high strain category. In the male group, 4.2% of the values were in the moderate strain category and no male experienced high strain (Schutte and Formanowicz, 2010). A limitation of this study was the small sample size and its composition.

2.2.1.3 RFA job categorisation

The RFA job categorisation provides information on the physical work requirements and workloads associated with mining occupations. The categorisation is based on the assessment (Louhevaara and Kilbom, 2005) and rating of the physical demands of tasks (Dictionary of Occupational Titles, 2003), and functional job analysis conducted by occupational therapists (Hofmann and Mohamed, 2011).

The classification of occupations into categories considers physical job demands such as manual material handling, the physical work environment (e.g. thermal loads and restricted ceiling heights) and whether the job is production related or not (Dictionary of Occupational Titles, 2003; Louhevaara and Kilbom, 2005). Classification categories include ‘very hard’, ‘hard’, ‘light’, ‘sedentary’ and ‘roaming’. For purposes of the current project only ‘very hard’ and ‘hard’ categories were considered.

According to the Dictionary of Occupational Titles (2003) and Louhevaara and Kilbom (2005), an occupation is classified as ‘very hard’ when:

- Manual material handling takes place for 34% to 66% of the work shift;
- Manual material handling takes place in restricted work environments (ceiling heights of between 0.85 m and 1.50 m);
- Daily exposure to high environmental heat loads occurs for more than 34% of the work shift; and
- Work tasks are imposed by a process (directly linked to production).

According to the Dictionary of Occupational Titles (2003) and Louhevaara and Kilbom (2005), an occupation is classified as ‘hard’ when:

- Manual material handling takes place for 34% to 66% of the work shift;
- Manual material handling takes place in unrestricted work environments;
- Daily exposure to high environmental heat loads occurs for more than 34% of the work shift; and
- Work tasks are imposed by a process (directly or indirectly linked to production).

Underground occupations at gold and platinum mines that fall into the ‘very hard’ and ‘hard’ job categories are presented in Table 4 and Table 5.

Table 4: Occupations at gold mines falling into the 'very hard' and 'hard' job categories (Hofmann and Mohamed, 2011)

'Very hard' work	'Hard' work
Double drum winch operator	Development construction team
Hydraulic stope drill rig operator	PTV crew
Machine/rock drill operators (stope)	Development team leader
Miner's assistant (Cheesa)	Rock drill assistant
Mining team/Stope team worker	Fitter assistant
Mono winch operator	General equipping and construction team leader
Stope multi-task crew member	Machine operator/driller (development ends)
Vamping	Shaft timber man assistant
Water jet operator	Shaft timber team supervisor
	Stope team leader
	Underground assistant
	Shift overseer (production)

Table 5: Occupations at platinum mines falling into the 'very hard' and 'hard' job categories (Hofmann and Mohamed, 2011)

'Very hard' work	'Hard' work
Miner's assistant/Cheesa (stoping)	Winch erector
Stope team supervisor	Winch erector assistant
Stope timber	Developing machine operator
Scraper winch operator	Drill rig operator
Shaft timber	Drop raise operator
Shaft timber man assistant	Drop raise supervisor
Shaft timber team supervisor	Drop raise assistant
Stope machine operator	PTV team supervisor
Multi-task team member	Pipes, tracks, salvage and ventilation
Cleaning specialist	Wire meshing lacing team supervisor
Rock drill operator (stoping)	

2.2.1.4 Ergonomics-related factors that impact on ability to perform physical work

Mining at depth is associated with high levels of heat stress that result from the geothermal properties of the rock that is mined. Many mining tasks are performed in a work environment where the maintenance of a natural body posture is basically impossible (because of the geometry of the workplace) and where other ergonomics-related factors are present that impact on the ability to perform physical work (Schutte et al., 2003). Occupations where these factors could impact on the ability to perform physical work are presented in Table 6.

Table 6: Ergonomics-related factors that impact on ability to perform work (Schutte et al., 2003)

Occupation	Restricted posture	Manual materials handling	Vibration	Repetition	Force
Roof bolter operator	√	√	√	√	√
Shuttle car driver	√		√	√	√
Shearer operator				√	
Fitter (machine)	√				√
Fitter (underground)	√				√
Boilermaker	√		√		√
Cable repairer	√	√		√	√
Electrician (panel)	√				√
Electrician (motor)	√	√		√	
Scraper winch operator (mechanical)	√	√		√	√
Scraper winch operator (pneumatic)	√	√		√	√
Tugger winch driver	√			√	√
Monorope winch driver	√	√			√
Pneumatic rock drill operator	√	√	√	√	√
Mechanical loader operator	√			√	√
General stope team installing: Timber packs Pencil sticks Camlock jacks Blasting barricades	 √ √ √ √	 √ √ √ √		 √ √ √ √	 √ √ √ √
General stope team: Lashing Barring	 √ √	 √ √		 √ 	 √ √

From Table 6 it is evident that posture is a very prominent factor that could potentially influence work performance. Restricted vertical heights associated with thin tabular reef type mining in gold and platinum mines require workers to stoop, squat or kneel. Performance limitations are evident when workers need to adopt such unusual or restricted postures during the performance of physically demanding tasks (Gallagher, 2005). The combination of awkward postures with other risk factors, such as materials handling, for example, could pose a significant risk to workers (Gallagher, 2008). A restricted workspace can lead to overexertion and can also increase the worker's physical stress due to the minimal possibility of varying work methods (Drury, 1985).

2.2.2 Matrix of physical job requirements and ergonomics-related factors that influence ability to perform physical work in various occupations

Following a workshop by the project team, which consisted of work physiologists, ergonomists and occupational therapists (all with experience of the assessment of physical workloads and functional job analyses), to review the information contained in Section 2.2.1, a matrix of the job requirements and related ergonomics factors that influence the ability to perform physical work was compiled (see Table 7). The information used to compile Table 7 was based on research findings published in research reports and scientific journals and on direct observations made by occupational therapists during functional job analysis. Only occupations with high physical demands (i.e. falling in the 'very hard' and 'hard' categories) that are involved in thin tabular reef type mining were considered, as these occupations would be studied in detail as part of Enabling Output 3.

Table 7: Matrix of physical job requirements and ergonomics-related factors that influence ability to perform physical work in various occupations

Occupation	Maximum metabolic rate (> 180 W/m²)	Awkward body posture	Vibration	Carrying, lifting or lowering loads	Shovelling	Heat stress	RFA work classification*
Development construction team	√	√		√	√	√	Hard
Fitter assistant	NIA	√		√		√	Hard
Hydraulic drill rig operator (stope)	√	√	√	√		√	Very hard
Machine/rock drill assistant	√	√	√	√		√	Hard
Machine/rock drill operator (stope)	√	√	√	√		√	Very hard
Machine/rock drill operator (development)	√	√	√	√		√	Hard
Miner (stoper)	√	√				√	NIA
Miner’s assistant (Cheesa)	√	√		√		√	Very hard
Mining team/Stope team worker	√	√		√	√	√	Very hard
PTV crew	√	√		√	√	√	Hard
Shaft timber man assistant	NIA	√		√		√	Hard
Shaft timber team supervisor	NIA	√				√	Hard
Shift overseer (production)	√	√				√	Hard
Stope multi-task crew member	√	√		√	√	√	Very hard
Team leader (development)	√	√				√	Hard
Team leader (equipping and construction)	√	√				√	Hard
Team leader (stope)	√	√				√	Hard
Underground assistant	NIA	√		√		√	Hard
Vamping	< 180 W/m²	√			√	√	Very hard
Water jet operator	NIA	√	√	√		√	Very hard
Winch operator (double drum)	√	√	√	√		√	Very hard
Winch operator (mono)	√	√	√	√		√	Very hard

√ = Associated with occupation NIA = no information available * = Refer to 2.2.1 for definitions of ‘Hard’ and ‘Very hard’

2.2.3 Occupations to be assessed for physiological strain during fieldwork as part of Enabling Output 3

One of the outcomes of Enabling Output 1 was a list of 'high risk' occupations (in terms of physical work intensity and extreme environmental conditions) to be studied at a gold and a platinum mine as part of Enabling Output 3. This list was based on the findings contained in Sections 2.2.1 to 2.2.4 of this report and the occupations to be targeted for the assessment of physiological strain as part of Enabling Output 3 are given in Table 8. From Table 8 it is evident that not many female mineworkers are allocated to strenuous occupations at present.

Table 8: Underground mining occupations to participate in Enabling Output 3

Occupation	Females in occupation on project mines	
	Gold mine	**Platinum mine**
Development construction team	Yes	Yes
Fitter assistant		
Hydraulic drill rig operator (stope)		Yes
Machine/rock drill assistant		
Machine/rock drill operator (stope)		
Machine/rock drill operator (development)		
Miner (stoper)	Yes	
Miner's assistant (Cheesa)	Yes	
Mining team/Stope team worker	Yes	Yes
PTV crew		
Shaft timber man assistant	Yes	Yes
Shaft timber team supervisor		
Shift overseer (production)		
Stope multi-task crew member		
Team leader (development)		
Team leader (equipping and construction)	Yes	Yes
Team leader (stope)		
Vamping		
Water jet operator		
Winch operator (double drum)	Yes	Yes
Winch operator (mono)	Yes	Yes

It was noted that the titles of the occupations given in Table 8 might differ at the project mines. For this reason it was planned to consult mine management to ensure that miners performing identical tasks would be grouped together for comparative purposes.

3 Enabling Output 2: Obtaining of ethics clearance from a human research ethics committee for planned research activities that will involve mineworkers

The study protocol was approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand in Johannesburg (Clearance Certificate: Protocol number M060720) (Appendix A). The clearance certificate was extended for another five years on 24 August 2011.

4 Enabling Output 3: Field-based research *in situ* to assess the physiological strain experienced by male and female mineworkers in 'high risk' occupations as identified in Enabling Output 1

This phase of the project was aimed at assessing the physiological strain experienced by mineworkers in 'high risk' occupations (in terms of physical work as identified in Enabling Output 1) during their routine work underground at a gold and at a platinum mine, respectively. The original objective was to compare the physiological strain experienced by a group of 75 mineworkers at the gold mine and a group of 75 mineworkers at a platinum mine. The assessments were scheduled to take place in hot environments (a 'hot environment' is defined by the Department of Mineral Resources (2002) as any environment where the dry-bulb temperature is less than 37.0°C, with a wet-bulb temperature range of 27.5°C to 32.5°C).

A heat stress management programme was implemented at the project gold mine. The programme consists of two essential elements: the assessment of overall fitness to work in heat (as part of the mine's medical surveillance programme) and the natural progression towards heat acclimatisation underground while countermeasures (safe work practices) are implemented. Only mineworkers classified as being fit for work in hot conditions following appropriate medical and physical examinations (Department of Mineral Resources, 2002) were considered for this phase of the project.

Great difficulties were experienced in obtaining volunteers to participate in the study, especially in the platinum sector. Labour unrest at platinum mines around the country had a negative effect on attempts to find a project mine to assist with the project. As a result of this unforeseen circumstance the planned date for completion of Enabling Output 3 at a platinum mine was initially extended by the Safety in Mines Research Advisory Committee (SIMRAC) but later it was decided by SIMRAC to terminate this phase of the project in view of the fact that no platinum mine was in a position to assist.

From Table 8 it is evident that not many of the high risk occupations in terms of physical work intensity at the project mine were occupied by females. In addition not many female mineworkers at the gold mine volunteered for the study and the objective of comparing the physiological strain experienced by male and female mineworkers matched according to occupation was not achieved. The results presented in this report, based on information collected at the project gold mine, will nevertheless contribute to the broadening of the knowledge base of the physiological strain experienced by mineworkers.

4.1 Methodology and instrumentation

4.1.1 Recruitment of participants

The gold mine used as the project site was selected on the basis that it is typical of a deep level mine that uses conventional thin tabular reef type mining methods and is classified as a 'hot' mine, with wet-bulb temperatures ranging between 27.4ºC and 32.5ºC, and dry-bulb temperatures below 37.5ºC. Most of the 'high' risk occupations identified in Enabling Output 1 were part of stoping and development teams at the mine.

The mine management and employee representatives at the gold mine that participated in the study were briefed about the research in terms of its content, duration, procedures and expectations, and an opportunity was created for all concerns and queries to be addressed. Following the briefing, underground mineworkers were invited to volunteer for the study on the understanding that they were able to refuse to participate and, if they should decide to volunteer for the study, could withdraw from the study at any time. All participants who volunteered to participate in the study were issued with consent forms (attached as Appendices B to E) and offered a further opportunity to voice concerns and raise questions regarding the project. The consent form was made available in English, Zulu, Setswana and Sotho.

The content of the consent form was further explained to each individual who volunteered for the study in their preferred language before the consent form was signed. The fact that the participants were taking part voluntarily on the basis of informed consent and that no remuneration would be given for participation was emphasised.

The participants were required to report to the occupational health personnel at the host mine for an interview regarding their medical history. The aim of screening the volunteers was to ensure that no one suffered from any contraindications (as indicated in Appendices B to E) that would make the use of the ingestible thermo-sensor (part of the CorTemp™ Physiological Monitoring System used as the research instrument) inadvisable. If a contraindication was present, the individual was not allowed to participate in the study.

4.1.2 Occupations and workplace conditions

A total of 65 mineworkers (11 females and 54 males) classified as being fit for work in hot conditions volunteered to participate in the study. They were from underground occupations associated with high physical work intensities and performed their duties in 'hot' underground workplaces with environmental temperatures ranging between 27.5ºC and 32.5ºC wet-bulb, with dry-bulb temperatures not exceeding 37.0ºC (Department of Mineral Resources, 2002).

Only mineworkers on day shift volunteered for the assessment of physiological strain. The mineworkers that participated in the study were from a stoping section and a development section and their occupations are given in Table 9.

Table 9: Occupations of study participants

Stoping			Development		
Occupation	**Males**	**Females**	**Occupation**	**Males**	**Females**
Mining Team	9	2	Development/Construction Team	13	1
Miner/Stoper	0	1	Miner/Developer	1	0
Miner’s Assistant	3	0	Miner’s Assistant	1	0
Stoping Team Leader	3	1	Development Driller	5	0
Equipping Team Leader	1	0	Scraper Winch Operator	1	0
Stope Driller	10	0	Loco Operator	4	3
Scraper Winch Operator	3	1			
Mono Winch Operator	0	2			

Safe work practices recommended by the Department of Mineral Resources (2002) were in place in the ‘hot’ underground workplaces. These work practices included the monitoring of workplace environmental temperatures, the maintenance of acceptable work rates through work-rest cycles and self-pacing, and the regular consumption of drinking water.

4.1.3 Physiological status monitoring system

The CorTemp™ Physiological Monitoring System was used to determine the heart rate and core body temperature of each mineworker during her/his underground shift. The monitoring system consists of an ingestible thermo-sensor (to measure and transmit core body temperature), a POLAR® heart rate recorder and transmitter (worn as a chest strap), and a miniature ambulatory data recorder to capture data transmitted by the thermo-sensor and heart rate transmitter. The system monitors, records and reports real-time core body temperature (T_{re}) and heart rate (HR) in time correlation.

4.1.4 Data-collection procedures

Participants swallowed the ingestible thermo-sensor pill and were fitted with the POLAR® heart rate recorders and transmitters and ambulatory data recorders upon arrival underground at the waiting place of the work area before the team’s safety meeting commenced. Correct operation of the CorTemp™ Physiological Monitoring System was confirmed prior to participants’ commencing of their daily tasks and the system was worn for the full shift. At the end of the shift information recorded was retrieved for analysis.

Each mineworker was studied for a single shift while he/she was regularly engaged in his/her assigned tasks and no instructions were given to control the work pace as such control could interfere with the main focus of the study. The participants were observed throughout the work shift by researchers who, as far as reasonably practicable, recorded tasks and the times at which they were performed. Special consideration was given to safety and care was taken not to interfere with the subjects while they were executing their normal tasks.

The thermal environment where mineworkers were deployed was monitored regularly at representative locations throughout the shift using calibrated whirling hygrometers.

Data were collected during day shifts only.

4.1.5 Data management

HR and T_{re} values were recorded by means of the CorTemp™ Physiological Monitoring System at 20-second intervals. In order to consolidate the data and facilitate analysis, HR and T_{re} values were averaged over one-minute intervals and used to calculate values of the PSI developed by Moran and co-workers (1998).

The PSI incorporates HR and T_{re} values and was calculated as follows:

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

where T_{re0} and HR_0 are the initial T_{re} and HR, and T_{ret} and HR_t are simultaneous measurements taken at any time.

The PSI was categorised into various levels of physiological strain (shown in Table 10), as suggested by Moran and co-workers (1998).

Table 10: Categorisation of levels of physiological strain by PSI

Strain category	PSI value
No-to-little	0 – 2
Low	3 – 4
Moderate	5 – 6
High	7 – 8
Very high	9 – 10

HR data were categorised into the following heart rate zones: < 60 beats/min, 60-80 beats/min, 81-100 beats/min, 101-120 beats/min, 121-140 beats/min, > 110 beats/min and > 140 beats/min. T_{re} data were categorised into the following temperature zones: < 38°C; 38.0-38.5°C; 38.6-39.0°C; 39.1-39.5°C; and > 39.5°C.

4.1.6 Statistical analysis

Statistical calculations were performed with SAS 9.3 software. Descriptive statistics that comprised mean, standard deviation and range were calculated for each of the variables while frequency counts and relative percentages were determined for categorised data. For each one-minute interval observation for each participant the classifications of the pre-set levels for the heart rate, body temperature and PSI value were determined, and the number of times the person experienced each level was summarised. Note that these times would not necessarily be consecutive periods, but could be spread out over the whole shift. Summaries of levels recorded were created for each person, and descriptive statistics at these levels were recorded for the total group, as well as for the individual gender, stoping and development groups.

Finally, non-parametric statistical tests were carried out to determine if there were any statistically significant differences at the 95% significance level. The non-parametric Mann-Whitney U test (also called the Wilcoxon two-sample test) was carried out to test for such differences between genders and between the stoping and development groups. The Kruskal-Wallis test was carried out to test for overall differences in heart rate, body temperature and PSI values for different occupations within the stoping and development groups. The Kruskal-Wallis test is similar to the Mann-Whitney test, but is used to test for differences between more than two groups. Some statistically significant differences were found as indicated in the relevant tables in Sections 4.2.1 to 4.2.5.

4.2 Results and discussion

The results contained in this report are based on observations made during fieldwork to assess physiological strain during work at an underground gold mine. The fieldwork took place during the period January to April 2012.

Information on heart rates, body temperatures and PSI values was given for all mineworkers assessed (combined group), for females and males in the total group, for all mineworkers involved in stoping activities (stoping group), for all mineworkers involved in development activities (development group) and also for occupations such as mining team members in the stope, development and construction team members, stope rock drill operators and development rock drill operators.

4.2.1 Physical characteristics of participants

The physical characteristics of the mineworkers that participated in the study are given in Table 11.

Table 11: Physical characteristics of participants

Group	n*	Statistic	Age (yrs)	Mass (kg)	Height (m)	Body Mass Index
Females	10	Mean	36.0	76.9	1.6	30.5
		Range	25.0-50.0	58.0-92.0	1.5-1.7	22.1-37.5
Males	52	Mean	35.8	70.6	1.7	25.1
		Range	21.0-56.0	53.0-101.0	1.5-1.8	18.9-38.4

* Body dimensions of one female and two males were unavailable and not recorded.

The age of the female participants ranged from 25 to 50. Body mass and stature were between 58.0 and 92.0 kg, and 1.50 and 1.70 m, respectively. When compared with recent anthropometrical data of the general South African mining population (Schutte et al., 2007), the average body mass of females that participated in the current study was 8.9 kg higher than, and their body mass ranged between the 20th and 95th percentiles of, females in the general mining population. Their body stature ranged between the 5th and 95th percentiles of the general mining population. The Body Mass Index (BMI) values of the females ranged between 22.1 and 37.5, with a mean value of 30.5.

The age of the males that participated in the study ranged from 21 to 56. When compared with recent anthropometrical data of the general South African mining population (Schutte et al., 2007), their body mass range of 53.0 to 101.0 kg is within the 5th to 99th percentile range of males in the general mining population. As far as stature is concerned, they fell within the 5th and 95th percentile group of males in the general mining population. The BMI values of the males ranged between 18.9 and 38.4, with a mean value of 25.1.

4.2.2 Thermal conditions in workplaces

Environmental thermal conditions in the stope where the mineworkers performed their normal routine duties ranged from 17.0°C to 34.0°C wet-bulb (average 28.4°C), with dry-bulb temperatures ranging from 23.5°C to 35.5°C and averaging 30.1°C. In the development end the wet-bulb temperatures ranged from 13.5°C to 37.0°C (average 29.0°C) and the dry-bulb temperatures from 24.0°C to 37.5°C and averaging 32.2°C.

4.2.3 Physiological strain

The PSI developed by Moran et al. (1998) was used to describe the physiological strain experienced by mineworkers during routine mining operations. The PSI, based on heart rate and body core temperature, is representative of the combined physiological strain reflected by the thermoregulatory and cardiovascular systems during work in heat.

The various physiological strain levels experienced by the mineworkers surveyed are summarised Table 12.

Table 12: Distribution of physiological strain categories of respective groupings

Grouping	n	Physiological strain category			
		No-to-little	**Low**	**Moderate**	**High**
Combined group	65	66.7%	27.6%	5.4%	0.3%
Females	11	71.7%	27.3%	1.0%	0.0%
Males	54	65.6%	27.6%	6.4%	0.4%
Results of Mann-Whitney test for differences between female and male groups: p < 0.0001					
Development group	29	70.6%	25.0%	4.2%	0.2%
Stoping group	36	63.7%	29.5%	6.4%	0.4%
Results of Mann-Whitney test for differences between development and stoping: p < 0.0001					
Mining team	11	59.8%	30.0%	9.4%	0.7%
Development and construction team	14	65.8%	26.3%	7.5%	0.4%
Stope rock drill operators	10	65.1%	30.1%	4.7%	0.1%
Development rock drill operators	5	72.0%	26.5%	1.5%	0.0%
Results of Kruskal-Wallis test for differences between the above four groups: p < 0.0001					

From Table 12 it is evident that the physiological strain experienced by the mineworkers that participated in the study predominantly fell in the range from ‘no-to-little’ to ‘high’. The combined group experienced ‘no-to-little’ physiological strain for approximately 67% of the shift and ‘low’ levels of physiological strain for approximately 28% of the time. ‘High’ levels of physiological strain were exceptions and for all practical purposes negligible as they only represented 0.3% of the PSI values recorded in the combined group.

If the statistical significance level of 95% was taken (i.e. $p < 0.05$ indicates significant differences), then there was a statistically significant difference between the female and male groups ($p < 0.0001$). From the mean values it can be seen that females experienced lower levels of physiological strain. The development group was exposed to statistically significant lower levels of physiological strain compared to the stoping group ($p < 0.0001$). Statistically significant differences were also revealed in terms of physiological strain experienced by the mining team in the stope area compared to the development and construction team as well as between the mining team and stope rock drill operators ($p < 0.0001$). When further analysis was conducted to find the differences between these four groups, no significant differences in terms of physiological strain were observed between stope rock drill operators and development rock drill operators ($p = 0.0644$) or between the development rock drill operators and development and construction team ($p = 0.4616$).

4.2.4 Heart rates

The means and standard deviations for heart rates of the respective groupings are given in Table 13.

Table 13: Heart rates of respective groupings

Grouping	n	Heart rate (beats per minute)	
		Mean	**Standard deviation**
Combined group	65	91.9	24.6
Females only	11	91.1	21.1
Males only	54	92.1	25.3
Results of Mann-Whitney test for differences between female and male groups: p < 0.0001			
Development group	29	86.9	23.5
Stoping group	36	95.7	24.7
Results of Mann-Whitney test for differences between development and stoping: p < 0.0001			
Mining team in stope	11	98.4	26.9
Development and construction team	14	89.4	24.1
Stope rock drill operators	10	96.4	26.3
Development rock drill operators	5	94.1	22.7
Results of Kruskal-Wallis test for differences between the above four groups: p = 0.001			

The mean and standard deviation, respectively, of the pooled heart rate data for the combined group was 91.9 and 24.6 beats per minute. The corresponding values for the female only group and male only group were very similar and did not differ significantly in terms of statistics ($p = 0.321$). There were statistically significant differences between the development group and the stoping group ($p < 0.0001$) as well as between the mining team in the stope area and the development and construction team ($p < 0.0001$). Stope rock drill operators and development rock drill operators also showed a statistically significant difference ($p = 0.001$) in heart rate. The observed differences between mineworkers in a stoping area and those in a development area suggest that the latter experienced less cardiovascular strain as measured by heart rate responses.

Heart rate is a frequently measured indicator of physical stress experienced while performing physical work (Leithead and Lind, 1964). Minard (1973) found that impaired work performance in an industrial setting did not occur until the average heart rate over a full shift was 120 beats per minute or higher. The World Health Organization (1969) recommends a lower figure of 110 beats per minute whilst allowing brief excursions to above 120 beats per minute for fit, acclimatised individuals. According to Brouha (1967), a heart rate of 110 beats per minute in an industrial setting is considered to be the limit beyond which cumulative fatigue is likely to ensue. Saha and co-workers (1979) also proposed that the acceptable workload for sustained physical activity might be considered as 35% of the maximum aerobic capacity of workers, which corresponded to a working heart rate of 110 beats per minute in their study.

Most of the mineworkers in the current study experienced heart rates during the shift that were equal to or lower than the 110 beats per minute recommended by the World Health Organization (1969), Brouha (1967) and Saha and co-workers (1979). In the combined group 67.0% of the heart rates recorded were equal to or lower than 110 beats per minute, with the corresponding figures for the female and male groups being 82.6% and 75.8%, respectively. Considering that the study took place in environmental conditions considered to be thermally stressful (Department of Mineral Resources, 2002), it is highly likely that these workers were self-pacing (a requirement of the safe work practices associated with heat stress management) to lower cardiovascular strain (Kenney et al., 2012).

Self-pacing is an acknowledged protective mechanism against the effects of heat stress (Brake and Bates, 2002; Miller et al., 2011) and a reduction in the work rate and increase in rest periods (a likely scenario if self-pacing does occur) would result in a lowering of thermal and cardiovascular strain (Kenney et al., 2012). This finding of self-pacing is in accordance with the findings of studies conducted at an Australian underground mine (Brake and Bates, 2001), a German coal mine (Kalkowsky and Kampmann, 2006), and in a Canadian mechanised mine (Kenney et al., 2012), which also suggest that self-pacing may play a significant role in mitigating the level of physiological strain experienced by miners.

The relative risk of becoming fatigued while performing mining tasks using Brouha’s (1967) criterion was calculated by looking at the time (number of minutes) a heart rate of over 110 beats per minute was recorded out of the total time measured within the respective groups. The percentage of time that heart rates at above 110 beats per minute were measured for individual participants in respective groupings is given in Table 14.

Table 14: Percentage of time that heart rates at above 110 beats per minute were measured for individual participants in respective groupings

Grouping	n	% of time that heart rates were at above 110 beats per minute
Combined group	65	23.0%
Females only	11	17.4%
Males only	54	24.2%
Results of Mann-Whitney test for differences between female and male groups: p = 0.5118 (corrected for individual participant effects)		
Development group	29	16.5%
Stoping group	36	27.9%
Results of Mann-Whitney test for differences between development and stoping group: p = 0.0144 (corrected for individual participant effects)		
Mining team in stope	11	32.6%
Development and construction team	14	20.1%
Stope rock drill operators	10	32.6%
Development rock drill operators	5	21.7%
Results of Kruskal-Wallis test for differences between these four groups: p = 0.2886 (corrected for individual participant effects)		

Table 14 shows that the male group had a greater percentage of heart rates of above 110 beats per minute than the female group. From Table 14 it is also evident that mineworkers in the stope generally had a greater percentage of heart rates of above 110 beats per minute than their counterparts in the development area. However, the values in Table 14 are affected by the fact that not all individuals were measured for the exact same time periods. The statistical tests for significant differences between groups, namely the Mann-Whitney test for differences between two groups and the Kruskal-Wallis test for differences between more than two groups, were conducted taking into account such measurement period differences between individuals. The results from these tests showed that the differences were not statistically significant between the gender groups ($p = 0.5118$), but were statistically significant between the development and stoping groups ($p = 0.0144$). No statistically significant differences were found between the individual job categories listed in Table 14, although the differences between the two job categories in the stoping group were higher than for those in the development group, which confirms the differences measured within the whole of the two groups.

4.2.5 Body temperatures

Statistics on the core body temperatures of the mineworkers that participated in the study are given in Table 15. Table 15 contains information on the means and standard deviations of the different groups as well as the distributions of body core temperatures into the selected categories. The percentages were calculated as the number of minutes a temperature within a certain category was measured out of the total time measured.

Table 15: Statistics and distribution of body core temperatures

Grouping	n	Core temperature (°C)						
		Mean	Standard deviation	< 38.0	38.0 to 38.5	38.6 to 39.0	39.1 to 39.5	> 39.5
Combined group	65	37.3	0.6	91.3%	6.1%	1.2%	0.8%	0.6%
Females	11	37.5	0.4	89.6%	8.6%	1.3%	0%	0%
Males	54	37.3	0.6	91.7%	5.6%	1.0%	1.0%	0.7%
Results of Mann-Whitney test for differences between female and male groups on mean temperature: p < 0.0001								
Development group	29	37.3	0.6	91.9%	4.2%	1.1%	1.7%	1.1%
Stoping group	36	37.3	0.6	90.8%	7.7%	1.2%	0.1%	0.2%
Results of Mann-Whitney test for differences between development and stoping group in terms of mean temperature: p < 0.0001								
Mining team	11	37.3	0.7	88.3%	9.3%	2.4%	0%	0%
Development/construction team	14	37.4	0.8	83.7%	7.9%	2.3%	3.7%	2.4%
Results of Mann-Whitney test for differences between mining team and development team in terms of average/mean temperature: p < 0.0001								
Stope rock drill operators	10	37.2	0.6	94.0%	6.0%	0%	0%	0%
Development rock drill operators	5	37.3	0.4	100%	0%	0%	0%	0%
Results of Mann-Whitney test for differences between stope rock drillers and development rock drillers in terms of mean temperature: p < 0.0001								

There was a statistically significant difference between the body core temperatures recorded in the female and male groups ($p < 0.0001$), with the values in Table 15 indicating that females experienced lower had lower body core temperatures. The development group had statistically lower body core temperatures compared to the stoping group ($p < 0.0001$). Statistically significant differences were also revealed in terms of the body core temperatures of the mining team in the stope area compared to the development and construction team as well as between the mining team and stope rock drill operators ($p < 0.0001$), between stope rock drill operators and development rock drill operators ($p < 0.0001$) and between the development rock drill operators and development and construction team ($p < 0.0001$). It should be noted that the hydration status of mineworkers was not measured in this study, and it is possible that differences in hydration status among the different occupations may have influenced the level of thermal strain experienced by the miners (Sawka et al., 2001).

The commonly recommended limits for industrial hyperthermia in terms of limiting (maximum) deep body core temperature are 38.0°C for a general population and 38.5°C for medically screened, acclimatised individuals (American Conference of Governmental Industrial Hygienists, 2011; Brake and Bates, 2002). All of the mineworkers that participated in the study had successfully completed a purpose-designed medical examination, a heat tolerance screening test and a period of natural acclimatisation underground (Department of Mineral Resources, 2002), and were considered to be ‘medically screened, acclimatised individuals’. The recommended limiting deep body core temperature of 38.5°C would therefore be applicable to them.

The percentage of times that body core temperatures exceeded 38.5°C in the current study is given in Figure 1 for the various groups.

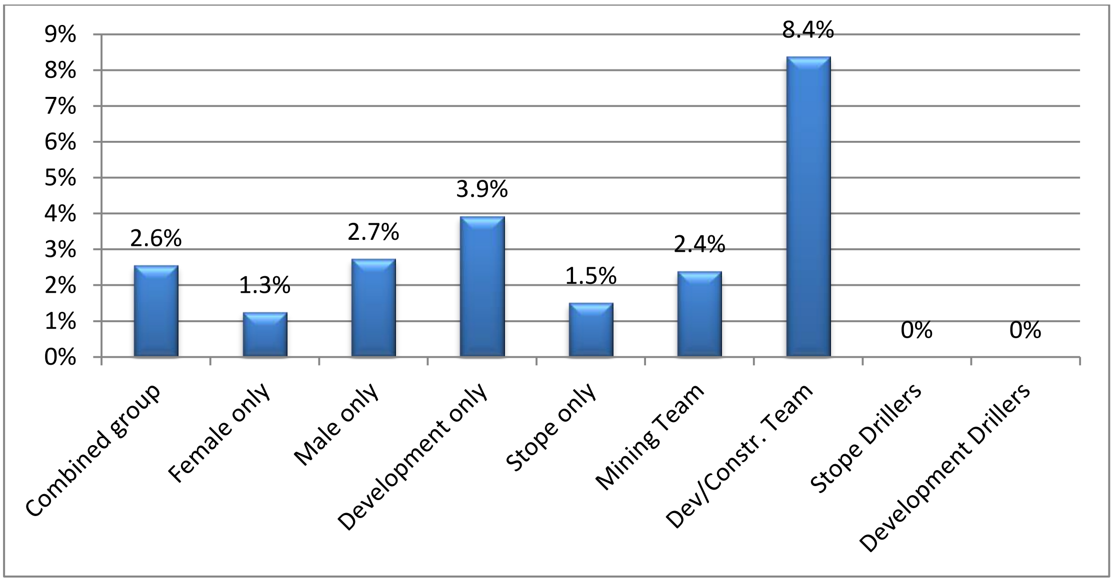

Figure 1: The percentage of times that body core temperatures exceeded 38.5°C

No significant differences in terms of the percentage of time a body core temperature of above 38.5°C was measured were found between any of the gender, team or occupation groups. This could be due to the very small proportion of high temperatures measured. For only 10 of the participants was a core temperature of above 38.5°C measured at any time during the measurement period.

4.2.6 Conclusion

The results obtained at the project gold mine indicate that the levels of physiological strain (as refelected by the thermoregulatory and cardiovascular systems) exhibited by the male and female mineworkers while performing their routine duties underground were not excessive. Given the environmental conditions and the physical nature of the tasks associated with the occupations assessed, it appears that the heat stress management procedures (Department of Mineral Resources, 2002) implemented by the project mine have played an important role in the levels of physiological strain observed.

Self-pacing, which is basically a ‘reduction in the average rate of work’, played a significant role in mitigating the level of physiological strain experienced by miners. As physical work is the main source of heat production in the body, this means that the work rate must be adjusted to restrict heat generation to a level at which heat storage does not occur. This can be achieved either by reducing work intensity, i.e. by self-pacing, or, if this is not possible, by work–rest cycling (Miller et al., 2011). Self-pacing has also been observed in other mining environments (Brake and Bates, 2001; Kalkowsky and Kampmann, 2006, Kenney et al., 2012). In all instances self-pacing played a significant role in mitigating the level of physiological strain experienced by miners.

The major limitation of this study is the relatively small sample size and its composition. Results presented in this report are based only on information collected at a gold mine. Labour unrest at platinum mines around the country had a negative effect on attempts to find a project mine to assist with the project and mineworkers in this sector were not assessed.

5 Enabling Output 4: The formulation and theoretical evaluation of a holistic approach to manage excessive levels of physiological strain and make workloads compatible with the physical capacities of workers

5.1 Ergonomics-based strategy

The physiological strain experienced by a mineworker while performing mining duties in hot areas is the overall physiological response that results from heat stress. The physiological responses are dedicated to dissipating excess heat from the body to keep body temperature in a safe range (American Conference of Governmental Industrial Hygienists, 2011). Heat stress is the net heat load to which a worker may be exposed and results from the combined contributions of work-related factors such as the metabolic heat from work and environmental factors such as air temperature, humidity, air movement and radiant heat exchange (Moran et al., 2002). Any strategy for managing excessive physiological strain when working in heat should therefore consider work-related factors.

The management of physiological strain caused by work-related factors should preferably be based on ergonomics’ principles. Ergonomics can be defined briefly as a systematic and rational means of designing tasks and workstations to be compatible with the needs, abilities and limitations of people.

From an ergonomics’ viewpoint two control strategies are available: engineering controls and work practice controls. In the present context engineering controls should be aimed at reducing metabolic rates associated with mining tasks through the application of sound ergonomics design principles. Work practice controls involve procedures and methods for adjusting work to avoid excessive physiological strain.

5.1.1 Ergonomic design

Mining equipment and tasks are frequently designed for functionality only without considering basic ergonomics' principles such as the anthropometry and functional strength of users (James et al., 2008). The ergonomic design of workstations and tasks, based on the physical abilities and limitations of mineworkers, can play a major role in the reduction of physiological strain. Information on the functional anthropometry of South African miners (i.e. those body dimensions that are essential for the design of workstations and mining equipment) and functional biomechanical strength capabilities (that are common to many occupational tasks in mining) is available for both male and female mineworkers (Schutte et al., 2007). The observed difference in functional strength in the aforementioned report is a very strong motivator for the ergonomic redesign of work that involves manual handling, in order that the workload can be optimised and made compatible with the physical capacity of male and female mineworkers, thereby reducing physiological strain. Guidance on the ergonomic design of mining tasks and tools to ensure that humans can perform safely, efficiently and without undue physiological strain is available (Kroemer et al., 1994; van Tonder and Schutte, 2001; James et al., 2008).

The actual workplaces in deep level mines present unique challenges for ergonomics' interventions. Mining takes place in very restrictive work areas with low ceiling heights and tasks are performed in postures that are not desirable and contribute to physiological strain. Research has shown that work in restricted postures is associated with a substantial decline in the physical capabilities of workers. Lifting capacity and strength are both significantly reduced in restricted postures compared to what can be achieved when standing. This suggests that loads that must be manually handled should be reduced compared to loads lifted in an unrestricted standing posture. In general, the data suggest that a 20% to 30% reduction in load should be put into effect when workers adopt restricted postures in order to reduce the risk of overexertion (Gallagher et al., 1988).

5.1.2 Work practices

The maintenance of acceptable levels of physiological strain in hot environments is possible through the adoption of work practices that focus on self-pacing and the prevention of dehydration, such as the safe work practices that are part of current heat stress management procedures in South African mines (Department of Mineral Resources, 2002).

Self-pacing

In hot environments workers who produce metabolic heat faster than physiological mechanisms and environmental conditions permit the heat to be lost will experience a rise in body core temperature and ultimately severe physiological strain. As physical work is the main source of heat production in the body, this means that the work rate must be adjusted to restrict heat generation to a level at which heat storage does not occur. This can be achieved either by reducing work intensity, i.e. by self-pacing, or, if this is not possible, by work–rest cycling (Miller et al., 2011).

Self-pacing is an acknowledged protective mechanism against the effects of heat stress (Brake and Bates, 2002; Miller et al., 2011) and a reduction in the work rate and increase in rest periods (a likely scenario if self-pacing does occur) would result in a lowering of thermal and cardiovascular strain (Kenney et al., 2012). Individuals who are able to self-pace will adjust their work rate to the conditions and, in this way, avoid physiological strain (Brake and Bates, 2002; Kalkowsky and Kampmann, 2006).

In a self-pacing approach, it is essential that management recognises the role of self-pacing as a protective behaviour in thermally stressful conditions and allows for it to take place. This may require permitting more frequent rest breaks and, to be successful, workers in hot environments need to be taught to recognise and respond to signs of heat strain in themselves and others.

Prevention of dehydration

Ensuring that workers are adequately hydrated is one of the most effective interventions for managing the physiological strain associated with working in hot environments (Miller and Bates, 2010).

Physical work increases heat production in the body. An adequate level of hydration is essential to dissipate this heat, with the blood plasma acting both to transport heat to the body surface and as the source of the fluid lost in sweating. Failure to replace fluid losses reduces plasma volume and compromises the ability of the circulatory system to maintain sufficient blood flow simultaneously to the skin and the working muscles, which leads to muscle fatigue, increases in body temperature and ultimately excessive levels of physiological strain (Miller and Bates, 2010).

Maintaining sufficient levels of hydration is imperative for preventing excessive levels of physiological strain while working in heat. Unfortunately many heat-exposed workers disregard recommendations for frequent fluid consumption and do not voluntarily drink enough water to replace the sweat loss in hot environments (Armstrong et al., 1985). Under such circumstances workers develop voluntary dehydration simply because they do not ingest sufficient fluid to offset their losses from sweating and urination. Thirst is an inadequate stimulus to drinking and this further contributes to the development of voluntary dehydration. It should be noted that the development of dehydration while working in heat may also be involuntary and the result of the non-availability of water in workplaces (Clapp et al., 2002).

The key to ensuring proper hydration levels while working in heat is to start work in a well-hydrated state and to maintain this, if necessary, with scheduled drinking. The more severe the thermal environment, the greater the potential benefits from improvements in the hydration status of workers.

The establishment of a culture of ‘hydration awareness’ among mineworkers exposed to work in hot environments is an essential part of the effort to manage physiological strain.

This may require changing of habitual behaviours in relation to the timing and quantity and type of fluid ingested, the objective being to start the work shift in a well-hydrated state and to maintain this by consuming fluid during the work shift.

Fluid consumption during the work shift cannot be left to voluntary drinking. Minimum fluid intakes must be prescribed and strategies put in place to ensure compliance and that water is available at the place of work. The current recommendation for the South African mining industry is that fluid replacement beverages (preferably only water or hypotonic fluids) be available at the place of work and that a fluid replacement regimen of at least 2 x 250 ml – 300 ml per hour be observed. The water should be cool (about 15°C), palatable and of good quality (potable) (Department of Mineral Resources, 2002).

Where sweating is exceptionally heavy or for prolonged physical work in heat there can be advantages to using electrolyte replacement beverages, which provide some carbohydrates as well (Clapp et al., 2002). The beverage chosen should be one that is formulated specifically for industrial use rather than products designed for sportsmen, which are frequently high in carbohydrate content because the maintenance of blood glucose levels during heavy exercise is a priority (Miller and Bates, 2010). In an industrial setting where high volume consumption of fluid is a priority, the use of the latter products can lead to an excessive calorie intake and, considering that a large portion of the South African population is overweight, the additional calories in beverages can be detrimental, in the long run, to the health of some workers.

5.2 Selection on the basis of physical attributes

Good ergonomic design of workplaces and tasks is the primary strategy for preventing excessive physiological strain experienced by female and male mineworkers in the underground environment. However, when technical and physical constraints in the mining environment hinder the implementation of this strategy, the selection of workers on the basis of physical abilities could become part of a comprehensive plan for reducing excessive levels of physiological strain associated with mining tasks. Under these circumstances it is necessary to maximise the fit between the person and the work environment in the interest of health and safety.

The Mine Health and Safety Act (Act 29 of 1996) requires employers to establish and maintain a system of medical assessments and surveillance of employees exposed to health hazards. In the present context physically demanding or strenuous work has been identified as a potential health hazard in the mining industry.

Any assessment aimed at ensuring that mineworkers meet the minimum standards to perform work should not discriminate against mineworkers on the basis of their gender. In order to achieve this objective an appropriate risk assessment tool to determine physical and functional work capacity, normalised for females and males, must be incorporated into medical assessments. High risk occupations, in terms of physical and environmental demands and the concomitant physiological strain, must also be identified.

6 Recommendations

Based on results obtained at the gold mine, the maintenance of acceptable levels of physiological strain in hot environments is possible through the adoption of work practices that focus on self-pacing, the prevention of dehydration and the adherence to applicable heat stress limits. It is recommended that these work practices also be implemented at ‘cool’ work areas (wet-bulb temperatures below 27.5°C) to prevent the development of excessive levels of physiological strain in work categories associated with high physical work loads.

The ergonomic design of workstations and tasks, based on the physical abilities and limitations of female and male mineworkers, can play a major role in the reduction of physiological strain, particularly when it comes to manual handling tasks. It is recommended that this aspect be incorporated into ergonomics’ programmes.

The major limitation of the current study is the relatively small sample size and its composition, and that mineworkers from a platinum mine did not participate in the study as originally planned. In order to broaden the knowledge base of the physiological strain experienced by male and female mineworkers involved in thin tabular reef type mining, it is recommended that workers from a ‘hot platinum mine (wet-bulb temeperatures ranging between 27.5ºC and 32.5ºC wet-bulb, with dry-bulb temperatures not exceeding 37.0ºC) also be studied when the industrial relations’ climate in the platinum sector has normalised and a suitable project mine has been identified.

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8 Appendix A: Human Research Ethics Committee (Medical) of the University of the Witwatersrand in Johannesburg (Clearance Certificate: Protocol number M060720)

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Schutte

CLEARANCE CERTIFICATE	PROTOCOL NUMBER M070620
PROJECT	The Relationship between Physiological Strain and Physical Work Requirements in Underground Mines (New title)
INVESTIGATOR	Mr PC Schutte
DEPARTMENT	OH & ERU/CSIR
DATE CONSIDERED	07.06.29
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 24/08/2011

CHAIRPERSON ....
(Professor P E Cleaton Jones)

*Guidelines for written 'informed consent' attached where applicable

cc: Supervisor : Prof MH Ross

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10005, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

9 Appendix B: Research Information Document and Consent Form (English version)

Study title: The relationship between physiological strain and physical work requirements in underground mines

Introduction: Research is the process we go through to establish the answer to a question. In this study we want to learn more about your bodies' reaction while you are working in a hot environment underground. This study is a research project and the answers that we get will help us to look at ways of identifying the high risk tasks in the mining industry and in this way help to make miners' jobs safer where necessary.

We are researchers working for the Human Factors Research Unit at the CSIR Centre for Mining Innovation (CMI). We are doing the research on behalf of the Mine Health and Safety Council and the project has been approved by a tripartite committee consisting of representatives from the Unions, Employers and Government. Our research is basically the collection of information on peoples' bodies' reaction to work that we can use to introduce ways to make jobs easier and safer.

As miners you are aware that the work that you are doing can sometimes be very difficult, especially when you are working in hot environments. In this study we want to measure the heart rate and body temperatures of miners while they are working. Heart rate and body temperatures will tell us what physiological strain miners are experiencing during normal mining tasks. This information will help the research team to look at ways to make the miners' jobs easier where there are high levels of physiological strain.

Invitation to participate: We are inviting you to take part in this research study, as we cannot do this research without the assistance of volunteers such as yourselves. As a volunteer in this study you would be asked to undergo a medical examination by our consulting occupational medical practitioner, at no expense to you, to check that you meet the required standard of fitness to take part in this study. If you do not qualify you will be advised on the reasons and be suggested for exclusion and counselled as necessary.

What is involved in the study? The aim of the study is to determine the physiological strain experienced by the bodies of male and female mineworkers during routine mining operations and underground conditions. In order to do this we would like to measure your heart rate and body temperature during an underground shift while you are performing your normal tasks. Your heart rate and body temperature will be measured for one shift only.

The equipment that will be used to measure your heart rate and body temperature responses is called the *CorTemp™ Physiological Monitoring System* and it functions in the following way:

Your heart rate will be measured by means of sensors that are in a thin rubber belt that you would wear around your body at chest level. A member of the research team will assist you in positioning the belt. When you have completed your shift the research team member will collect the belt from you.

Your body temperature will be measured by means of a capsule (ingestible thermometer pill) that you would be asked to swallow. Once inside your body the capsule will transmit your body temperature to a small data recorder that you would be asked to wear around your waist. The capsule you would be asked to swallow is safe and can be swallowed as any other capsule. The capsule will not dissolve and will remain in your body for approximately 18 to 30 hours, before passing out of your system safely.

If you decide to participate in the study the medical doctor on the project team would like to interview you to ensure that there are no medical reasons why you cannot swallow the pill. If there is any medical reason why you cannot swallow the pill you will not be allowed to participate in the study.

The use of the ingestible thermometer pill is not recommended under the following conditions:

- If your body mass is less than 40 kg;
- If you have any problems swallowing;
- If you have any abnormalities of the oesophagus – that is the part of your throat between your mouth and stomach when you swallow;
- If you have problems with your gag reflex (the gag reflex is the choking or vomiting feeling you get if something touches the back of your throat);
- If you have any obstructive diseases of the stomach or bowels;
- If you have ever had stomach surgery;
- If you have ever had problems with lazy bowels;
- If you have a heart pacemaker or other implanted electromedical device; or
- If you are scheduled to undergo any special x-rays (NMR/MRI scanning) within the next week.

A total of eighty miners from your mine will be invited to participate in the study.

Risks: The study conditions that you would be exposed to have been carefully determined so as to ensure that you would not be put under an excessive amount of stress. This, coupled with the medical examination and interview, would ensure that no risk is posed to your health. However, a medical professional will be present throughout the assessment steps on each test day. You would be required to report any discomfort you may experience during or after the study to a research team member or to the medical practitioner. It will then be ensured that you are medically examined and treated if required; the cost of the examination will be at the expense of the study.

Benefits: There would be no direct benefits to yourself for your participation in the study. However if the physiological strain level are judged to be excessive, ergonomics intervention will be recommended to facilitate ease of work and to ensure a healthy work environment.

Pertinent information: You would be free to ask questions to the research team at any time. Your physiological results would be available to you on the day after the assessment days.

Participation is voluntary: Taking part in the study is voluntary. You are free to refuse to take part in the study or to withdraw from the study at any time without penalty.

Reimbursements: There will be no extra compensation for participation in the study as it will take place during your normal shift.

Confidentiality: Care will be taken to maintain confidentiality so that you are not identifiable to people who are not involved in the research. Personal identifying data (name and identity number) will not be recorded on data sheets. Confidential information will be locked in filing cabinets, or, if held on a computer, password protected. Only collective data will be used in reports to the sponsors and feedback sessions.

Absolute confidentiality cannot be guaranteed and personal information will have to be disclosed if required by law. Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the Research Ethics Committee, for example.

Contact details of researchers:

CSIR Centre for Mining Innovation (CMI)	*Tel: 011 358 0000*
Schu Schutte, CSIR CMI (Project Leader)	Tel: 011 358 0202
Lesedi Milanzi, CSIR CMI (Team member)	*Tel: 011 358 0253*
Tanya Grové, CSIR CMI (Team member)	*Tel. 011 358 0258*
Tebogo Moraba, CSIR CMI (Team member)	*Tel. 011 358 0000*

Contact details of ethics administrator:

Ms Anisa Keshav
Secretary: Human Research Ethics Committee (Medical)
Tel: 011 717 1234
E-mail: keshava@research.wits.ac.za

Declaration of participant: I, ______________________ confirm that I have read this document and that I understand its contents. I declare that I have been fully informed and that I hereby consent to voluntarily participate in this study and understand that I can stop participation in the study at any stage without experiencing duress from any parties; furthermore, that I have been given the opportunity to ask questions regarding these procedures and that I can ask questions at any time of the research team.

Signatures of participant and witness

____________________________ ____________________________
Signature of participant Date

____________________________ ____________________________
Signature of witness Date

Declaration of research members: I have fully explained the procedures to be followed during the research project. I have provided the opportunity for the participants to ask any questions or raise any concerns and have answered these to the best of my ability. All reasonable actions have been taken to ensure the safety and wellbeing of the participants for the duration of the project.

Signature of research team member	Date
Signature of research team member	Date

10 Appendix C: Research Information Document and Consent Form (Zulu version)

Imininingwane yocwaningo neform lemvume.

Isihloko salolucwaningo: Ubudlelwane phakathi kokukhandleka komzimba kanye nomsebenzi odinga amandla phansi kwizimayini.

Isingeniso: Ucwaningo yilapho sithola khona indlela yokungenelela ukuze sikwazi ukusungula impendulo embuzweni othile. Kulolucwaningo sifuna ukwazi kabanzi mayelana nokusebenza kwemizimba yenu ngenkathi nisebenza endaweni eshisayo ngaphansi kwemayini. Lolu cwaningo kanye nezimpendulo esizozithola zizosisiza ukuthi sibhekekisise izindlela zokwazi ubungozi yemisebenzi eyenziwayo kwezezimayini liphinde lisisize ukuba sithole izindlela zokwenza imisebenzi yasezimayini iphephe lapho okunesidingo khona.

Singabacwaningi abasebenzela I Huma Factors Research Unit e CSIR Center for Mining and Innovation(CMI). Senza ucwaningo ngokucelwa I Mine Health and Safety Council. Lolu cwaningo luvunywe ikomidi okubalwa kuzo izikhulu ezithize kwezenhlangano,yabasenzi kanye nohulumeni. Ucwaningo lwethu kahle hle ukuthatha imininingwane emzimbeni yabantu ngalesisikhathi besebenza ukuze sikwazi ukuveza izindlela zokwenza umsebenzi ubengcono futhi uphephe.

Njengabasebenzi basezimayini siyazi ukuthi kunemisebenzi kwesinye isikhathi ebuye ibenzima kakhulu, kakhulukazi umangabe usebenzela endaweni eshisayo. Manje kulolu cwaningo sifuna ukukala ukushaya kwenhliziyo kanye nokushisa komzimba kubasebenzi basezimayini ngalesikhathi besebenza. Ukushaya kwenhliziyo nokushisa komzimba wakho yikhona okuzositshela ukuthi basebenzi basezimayini bezwa ukukhandleka okungakanani ngalesikhathi besebenza. Lemininingwane izosiza ithimba lezocwaningo ukubheka izindlela ezingenza gcono zokwenza ukuthi imisebenzi yasezimayini ibelula lapho khona kunezinga eliphezulu lokukhandleka.

Isimemo sokungenelela: Siyakumema ukuba ungenelele kulolu cwaningo njengoba singeke sikwazi ukwenza ucwaningo ngaphandle kosizo lwenu nangokuzinikela kwenu. Njengomuntu ozinikeleyo kulolu cwaningo uzocelwa ukube uyoxilongwa abezempilo ngaphandle kwezindleko zakho ukuze bakwazi ukuthola ukuthi ukulungele yini ukungenelela kulolu cwaningo umangabe kutholakale ukuthi awukulungele uzonikwa izizathu ezenze lokho angeke futhi ubeyingxenye yocwaningo, umangabe kunesidingo sokwelulekwa uzolulekwa.

Yini ebandakanya lolucwaningo: Inhloso yalolucwaningo ukuthola izinga lokukhandleka komzimba emzimbeni yabesilisa nabesifazane emisebenzini yasezimayini ngalesikhathi besenza ngaphansi. Ukuze sikwazi ukwenza lokhu sidinga ukukala ukushaya kwenhliziyo yakho kanye nokushisa komzimba wakho ngalesisikhathi usebenza. Ukushaya kwenhliziyo kanye nokushisa komzimba wakho kuzokalwa ngalesikhathi usebenza.

Izinto ezizobe zisetshenziswa ukukala kokushaya kwenhliziyo nokushisa komzimba wakho kubizwa ngokuthi I CoreTemp Physiological Monitoring System isebenza ngalendlela elandelayo.

1. Inhliziyo yakho izobe ikalwa nge-sensors ekwi rubber encane eyibhande ozobe uyigqoke emzibheni wakho ngasesifubeni, omunye wethimba noma ophethe uzokusiza ukukutshengisa ukuthi ibhande kumele ulibeke kanjani, umangabe usuqedile umsebenzi wakho enye yezingxenye zethimba lezocwaningo izobe isithatha ibhande kuwe.
2. Ukushisa komzimba wakho kuzobe kukalwa nge philisi eligwinyekayo futhi uzobe usucelwa ukuthi uligwinye. Umangabe leliphilisi selingaphakathi emzimbeni wakho lizobe selendlulisa ukushisa komzimba wakho kwi-data recoder uzobe ucelwe ukuthi uyifake okhalweni lwakho

   Leliphilisi uzocelwa ukuba uligwinye liphephile futhi ungaligwinya njengamanye amaphilisi, leliphilisi angeke ligcibilike lizohlala emzimbeni wakho cishe amahora awu-10 kuya kawu 30 ngaphambi kokuba liphume kuwe ngokuphephile

Umangabe uthatha isigqumo sokungenelela kulolucwaningo udokotela walomsebenzi wethimba uzobe esekubuza imibuzo ukuze aqinisekise ukuthi ngempela azikho yini izizathu ezingenza ukuthi ungakhoni ukugwinya iphilisi. Umangabe kukhona izizaba noma izizathu ezithize zokuthi kungani ungakhoni ukugwinya iphilisi angeke uvumeleke noma awuvumelekanga ukungenelela kulolucwaningo.

Ukusetshenziswa kwephilisi akuvumelekanga ngaphansi kwalezi zimo ezilandelayo:

- Umangabe isisindo sakho singaphansi kuka 40 kg
- Umangabe unenkinga yokugwinya
- Umangabe unokukhubazeka okuthile komgudu wokudla lapho kuyingxenye yakho yomphimbo maphakathi komlomo nesusu uma ugwinya.
- Umangabe unenkinga yokugwinya uzwa sengathi ungahlanza
- Umangebe unesifo esithile esithikameza isusu sakho
- Umangabe uke wayohlinzelwa isisu
- Umangabe ukewaba nenkinga ye heart peacemaker
- Umangabe uhlelelwe ukuthi uzoya kwi X-Rays ngaphaphi kwamaviki amabili

Bangu -80 abasenzi basezimayini abazocelwa ukuba bengenelele kulolucwaningo.

Ubungozi: Isimo salolu cwaningo enizolungenelela lubhekisiswe kahle ukuze kubenesiqiniseko sokuthi ningabi ngaphansi kwengcindezi enkulu, lokho kuhlanganisa ukubhekwa noma ukuxilogwa ngodokotela kanye nemibuzo abazobe benibuza yona izosiza ukuthi kubhekwe ukuthi abukho yini ubungozi ngempilo yakho.ngalokhoke abezempilo bazobe bekhona njalo ngelanga lokuhlolwa. Uyacelwa ukuba ubikele abezempilo noma ithimba lezocwaningo umangabe ungazizwa kahle ngalesikhathi socwaningo noma emva. Kuzobe sekuqinisekiswa ukuthi uhlolwa yonke into uphinde welashwe umakunesidingo, izindleko zizobe zibheke laba abenza ucwaningo.

Inzuzo: Angeke kube nanzuzo ethile kuwe ngokungenelela kulolucwanoingo, kodwa-ke uma izinga lokukhandleka sithola ukuthi lendlulele, abocwaningo le-ergonomics bazobe sebenikwa igunya lokwazisa indlela egcono yokusebenza khona bezokwazi ukuqinisekisa indlela ephephile noma egcono yokusebenza.

Imininingwane ebalulekile: Uvumelekile ukubuza imibuzo kwithimba lezocwaningo nanoma ngasiphi isikhathi. Imiphumela yakho yokukhandleka izotholakala kuwe emva kosuku uqede ukuhlolwa kwakho.

Ukungenelela kwakho kungokokuzinikela: Ukungenelela kwakho kulolu cwaningo kuzobe kungokokuzinikela kwakho ngothando, uvumelekile ukwala ukungenelela kulolucwaningo noma ukuyekela kulolucwaningo nanoma ngasiphi iskhathi ngaphandle kwemibandela ethile.

Mayelana nemali: Angeke kube nanzuzo noma imali ngokungenelela kwakho kulolucwaningo njengoba izobe yenziwa ngezikhathi zakho ezijwayelekile zokusebenza.

Imfihlo: Sizobe sicophelisisile ukuthi ukungenelela kwakho kuyimfihlo ukuze ungezukwaziwa ngabantu abangasiyo ingxenye yalolucwaningo. Iminingwane yakho efana negama kanye nenombolo kamazisi noma yepasi angeke ibhalwe phansi. Imininingwane yakho eyimfihlo izokhiyelwa amakhabetheni noma umangabe ikwi computer kuzobe kunenombolo eyimfihlo futhi evikelekile. Imininingwane ezobe ithathwe kuwe kuphela ezosetshenziswa kumbiko kanye nemiphumela yayo.

Kodwa-ke ukuqiniseka kwemfihlo yemininingwano yakho akunasiqiniseko esingako kodwa ingakhishwa umangabe idingwa abezomthetho. Izinhlangano ezingakopisha ucwaningo mayelana nokwenza isiqiniseko kanye nokuthola isihlambululo kubalwa kubo i Research Ethics Commitee,

Imininingwane yabezocwaningo

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Ukuqinisekisa kozongenelela .Ngingu____________________ngiyaqinisekisa ukuthi ngiyifundile lemininingwane futhi ngiyazwisisa ukuthi ichazani noma isho ukuthini. Ngiyaqinisekisa ukuthi ngazisiwe futhi ngiyazi ukuthi ingxenye yami yokungenelela kulolu cwaningo ingokokuzinikela kwami, futhi ngiyazwisisa ukuthi ngingayeka nanoma yini ukuba yingxenye yalolucwaningo ngaphandle kokucindezelwa, futhi nginikiwe ithuba lokubuza imibuzo mayelana nezindlela, kanye nokuthi ngingabuza nanoma yinini.
Isigxivizo songenelelayo kanye nofakazi

Isigxivizo songenelelayo	usuku
Isigxivizo sikafakazi	usuku

Isiqinisekiso kowengamele ucwaningo: Ngichaze ngokuphelele yonke imininingwane ezolandelwa ngesikhathi kwenziwa ucwaningo. Ngibanikile ithuba abangenelele kulolucwaningo lokubuza nanoma yini, noma benezikhalazo ezithize futhi ngibaphendulile ngokuphelele. Zonke izizaba ezithile zithathiwe ukuqiniseka ukuphepha kanye nokuphatheka kahle kwabasengxenyeni yocwaningo ngalesisikhathi socwaningo.

Isigxivizo sowethimba lezocwaningo	usuku
Isigxivizo sowethimba lezocwaningo	usuku
Isigxivizo sowethimba lezocwaningo	usuku
Isigxivizo sowethimba lezocwaningo	usuku

11 Appendix D: Research Information Document and Consent Form (Setswana version)

Tokumente ya Tshedimosetso ka ga Patlisiso le Foromo ya Tumelano

Setlhogo sa thuto: Kamano magareng a kgatelelo ya tlhaloganyo le tiro ya diatla mo meepong.

Matseno: Patlisiso ke thulaganyo e e tseiwang go batlisisa karabo ya potso. Mo thutong e re batla go ithuta go go oketsegileng ka tsibogo ya mmele fa motho a dira mo lefelong le le mogote ka fa tlase ga lefatshe. Thuto e ke porojeke ya patlisiso mme dikarabo tse re di boneng di tla re thusa go lebelela ditsela tsa go tlhaola / supa ditiro tse di nang le dikotsi tse di kwa godimo mo industiring ya meepo, gape ka tsela eno e thusa go dira gore tiro ya moepi e nne e e sereletsegileng fa go tlhokegang teng.

Re babatlisisi ba ba direlang Unit ya Dipatlisiso tsa Difactor tsa Batho (Human Factor) ko sentareng ya Botlhami jwa Meepo (Centre for Minning Innovation). Re dira dipatlisiso mo maemomg a Council ya Boitekanelo le Tshireletsego ya Meepo, gape projeke e dumeletswe ke komiti ya dipathi di le tharo tse maloko a tsona e leng baemedi ba Diunione, Bathapi le Goromente. Patlisiso ya rona ke kokoanyo ya dintlha ka tsibogo ya mmele ya batho mo tirong . Dintlha tseno di ka dirisiwa jaaka matseno a mekgwa ya go dira ditiro go nna botlhofo le go sireletsega.

Jaaka badiri ba moepo lo a itse gore tiro e lo e dirang e ka nna thata gofitisa ka dinako dingwe, segolo fa le dira mo mafelong a a fisang. Mo thutong eno, re batla go lekanya lobelo lwa pelo le temperature ya mebele ya baepi fa ba dira. Dilo tse di tla re bolelela gore baepi ba itemogela kgatelelo e ka na kang fa ba dira tiro ya bona e e tlwaelegileng. Kitso e no e tla thusa setlhopa sa babatlisisi go lebelela ditsela tsa go dira tiro ya baepi bonolo fa go na leng kgatelelo e e kwa go dimo ya tlhaloganyo.

Taletso ya go tsaya karolo: Re go laletsa go tsaya karolo mo thutong ya dipatlisiso ka gonne ga re kitla re kgona go dira dipatlisiso kwa ntle ga thuso ya baithaopi ba ba tshwanang le lona. Jaaka moithaopi, mo thutong e, o tlile go kopiwa go dirwa diteko tsa boitekanelo ke ngaka kwa ntle ga tuelo, go bona gore a na o fitlhelela maemo a a batlegang a boitekanelo gore o kgone go tsaa karolo mo thutong e. Fa o sa a fitlhelele, o tla neiwa kgakololo ka mokgwa e e maleba mme wa kopiwa gore o seka wa tsaa karolo .

Ke eng se e leng karolo ya thuto e? Maikaelelo a thuto eno ke go batlisisa kgatelelo ya tlhaloganyo e e itemogelwang ke mebele ya banna le basadi ba baepi, mo nakong ya ditiro tsa bona tse di tlwaelegileng ka fa tlase ga lefatshe. Go dira seno, re batla go lekanya lobelo lwa pelo ya gago le temperature ya mmele, ka nako ya fa o leng ka fa tlase ga lefatshe, fa o dira tiro ya gago ya tlwaelo. Lobelo lwa pelo le temperature ya mmele wa gago di tla lekanngwa sebaka sa shift e le nngwe fela.

Sediriswa se se tla dirisiwang go lekanya lobelo lwa pelo ya gago le temperature ya mmele wa gago se bidiwa *CorTemp*™ Monitara wa Tsamaiso ya Mmele (Physiological Monitoring system). Yona e dira ka tsela e:

1.) Lobelo lwa pelo le tla lekangwa ka sensora ya lebanta lwa rubber lo lo sesane , lo o tla lo rwalang go dikologa mmele wa gago mo maemong a mafatlha. Leloko la setlhopha sa babatlisisi le tla go thusa go apara lebanta. Fa o fetsa nako ya gago ya tiro, leloko la setlhopha sa babatlisisi lo tla tsaa lebanta mo go wena.

2.) Temeperature ya mmele wa gago e tla lekanngwa ka capsule (pilisi e e sa silegeng ya thermometer) e o tla kopiwang gore o e metse. Fa ele ka fa gare ga mmele pilisi e tla romela temperature ya mmele wa gago ko rekoteng ya tshedimosetso e nnyane, e o tla kopiwang gore o e rwale mo lethekeng.

Pilisi e o tlo kopiwang gore o e nwe, e sireletsegile, e ka metsiwa jaaka pilisi nngwe le nngwe. Pilisi ga e kitla e tlhapologa, gape e tla nna mo mmeleng wa gago nako e e ka nnang diura di le somerobedi go isa go di le masome a mararo, pele e ka tswa mo mmeleng wa gago ka tshireletsego.

Fa o tsaa tshoetso ya go tsaya karolo mo thutong e, ngaka e eleng leloko la ba batlisisi, e tla batla go go botsa dipotso, go netefatsa gore ga gona mabaka a boitekanelo a a tla dirang gore o seka wa nwa pilisi. Fa go na le lebaka la boitekanelo le le kgoreletsang gore o nwe pilisi, ga o kitla o letlelelwa gore o tseye karolo mo thutong eno.

Tiriso ya pilisi ya thermometha e e sa silegeng, ga go gakololwe gore e dirisiwe ka fa tlase ga maemo a:

- Ga sekalo sa mmele wan gago sele ka fa tlase ga 40kg.
- Fa o na le mathata a go metsa.
- Fa o na le bokoa mo mometsong – seo ke karolo ya mometso magareng a molomo le mogodu fa o metsa.
- Fa o na le mathata a go batla go tlhatsa fa sengwe se kgoma lemorago la mometso wa gago.
- Fa o na le malwetse a a kgoreletsang mogodu le mala.
- Fa o kile wa nna le karo ya mogodu.
- Fa o na le mathata a mala a a tswafang.
- Fa o na le pelo e e jetsweng kgotsa sediriswa sa boitekanelo sa motlakase se; kgotsa
- Fa o tshwanetse go dira x-ray e e kgethegileng (Sekene sa NMR / MRI) mo lobakeng lwa beke e e tlang.

Baepi ba le lesome robedi batla lalediwa go tsaya karolo mo thutong eno.

Dikgwetlho: Maemo a thuto a o tla lebantshiwang le one, a tlhophilwe ka kelotlhoko go netefatsa gore ga o beiwe ka fa tlase ga seterese (stress) se le se ntsi. Seno, tlhatlhobo ya ngaka le go botsiwa dipotso, di tla netefatsa gore ga go na kgwetlho epe mo boitekanelong jwa gago. Le gale, moporofeshenale (professional) wa boitekanelo o tla nna teng ka nako yotlhe ya tlhatlhobo, letsatsi lengwe le lengwe. O tlile go kopiwa go itsese mongwe wa leloko la babatlisisi kgotsa ngaka, ka gosaiketlang go o go utlwang mo nakong le ka fa morago ga dithuto. Go tla netefatswa gore o a tlhatlhobiwa mme o alafiwe fa go tlhokega, tlhwatlhwa ya tlhatlhobo e tla duelwa ke babatlisisi.

Tuelo: Ga go kitla go nna le tuelo go wena o tsaang karolo mo dithutong. Mme fa kgatelelo ya tlhaloganyo e sekasekiwa go nna ntsi, intervention ya ergonomics e tla tshitshinngwa, go diragatsa gore tiro e nne botlhofo le go netefatsa gore lefelo la tiro le itekanetse.
Tshedimosetso e e botlhokwa: O golosegile go botsa dipotso go setlhopha sa babatlisisi nako nngwe le nngwe. O tla neiwa dipholo tsa gago tsa tlhatlhobo ya tlhaloganyo letsatsi morago ga matsatsi a tlhatlhobo.

Go a ithaopiwa go tsaa karolo: Fa o batla go tsaa karolo mo thutong, o a ithaopa**.** O letleletswe go gana go tsaa karolo mo thutong kgotsa go ikgogela kwa morago nako nngwe le nngwe kwa ntle ka kotlhao.

Participation is voluntary: Taking part in the study is voluntary. You are free to refuse to take part in the study or to withdraw from the study at any time without penalty.

Tuelo morago: Go tsaya karolo mo thutong ga go kitla go go naya tuelo e nngwe, gonne thuto e tla dirwa ka nako e e tlwaelegileng ya tiro.

Go tshwara dilo mo sephiring: Tlhokomelo e tla tseiwa go netefatsa gore ga o itsege go batho ba ba sa tseeng karolo mo patlisisong. Tshedimosetso ya gago, e e go itseseng (leina le nomoroitshupo) di ka se kwalwe mo pampiring ya tshedimosetso. Tshedimosetso ya sephiri e tla notlelelwa ka fa dikabineteng tsa difaele, fa di le mo komputareng, di tla sereletswa ka khunololamoraba (password). Tshedimosetso e e akaretsang ke yona fela e tla dirisiwang mo di pegelong tsa disponsara le mananeong a phetolo (feedback).

Kano ya sephiri ga e tshepisiwe, gape tshedimosetso ya gago e tla tshwanelwa ke go ntshiwa fa molao o e tlhoka. Ditlamo tse di ka tlhatlhobang le go kopa rekoto ya gago ya dipatlisiso go netefatsa boleng le tshekatsheko ya tshedimosetso, di akaretsa ditlhopa jaaka Komiti ya Mekgwa ya Dipatlisiso (Research Ethics Committee) jaaka sekai.

Nomoro ya mogala ya babatlisisi

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Kano ya motsaakarolo: Nna, ______________________ ke ikana gore ke buisitse tokumente eno le gore ke utlwisisa diteng tsa yona. Ke ikana gore ke boleletswe ka botlalo le gore ke dumela go tsaa karolo mo thutong eno kwa ntle ga kgapeletso. Ke tlhaloganya gore nka tlogela go tsaa karolo mo thutong nako nngwe le nngwe kwa nlte ga go tshosediwa ke ope. Gape, ke neilwe sebaka sa go botsa dipotso malebana le ditsamaiso, le gore nka botsa dipotso ka nako nngwe le nngwe go setlhopha sa babatlisisi.

Tshaeno ya batsaakarolo le dipaki

________________________	________________________
Tshaeno ya motsaakarolo	Letlha
________________________	________________________
Tshaeno ya paki	Letlha

Kano ya leloko la babatlisisi: Ke tlhalositse tsamaiso e e tshwanetseng go salwa morago mo nakong ya projeke ya patlisiso. Ke neile batsaakarolo sebaka sa go botsa dipotso kgotsa go ntsha dipelaelo tseo ke di arabileng go ya ka bokgoni jwa me. Dikgato tshotlhe tse di maleba di tserwe go netefatsa tshireletsego le boitekanelo jwa batsaakarolo mo nakong ya projeke.

________________________	________________________
Tshaeno ya leloko la setlhopha sa babatlisisi	Letlha
________________________	________________________
Tshaeno ya leloko la setlhopha sa babatlisisi	Letlha

Tshaeno ya leloko la setlhopha sa babatlisisi	Letlha
Tshaeno ya leloko la setlhopha sa babatlisisi	Letlha

12 Appendix E: Research Information Document and Consent Form (Sotho version)

Hlaloso ka ga resetshe le lengwalo la tumelelano
Hlogo ka ga resetshe: Tswalano magareng ga ngangego ya popommele le mohuta wa mosebetsi o o hlokagalago maeneng
Matseno: Resetshe ke tsela yeo e berekisiwago go hwetsa di karabo. Mo resetsheng ye, re leka go hwetsa go gontsi ka ga mmele wa gago le go fetoga ga ona ge o le mosebetsing mo go fisago tlase mokoting. Dikarabo tse re tlilego go di hwetsa mo, di tlo re thusa go supa gore ke efe mesebetsi e kotsi maeneng gore re kgone go oketsa polokego ya basebetsi ba maene.
Re diresetshas go tswa go Human Factors Research Unit ko CSIR Centre for Mining Innovation (CMI). Re dira resetshe legatong la Mine Health and Safety Council . Projeke e e dumeletswe ke mekgahlo e meraro e lego baemedi ba Union, Bathwali ba maene le Mmuso. Resetshe ya rena e amana le go kgoboketsa sedi ka ga mmele wa motho ge a sebetsa gore re kgone go dira gore mesebetsi e be bobebe le go bolokega.
Ka ge le le babereki ba maene, le a tseba gore tiro ye le e dirago e boima ka nako e nngwe, kudu ge le direla lefelong leo le fisago. Mo resetsheng ye, re nyaka go mesara go kiba ga pelo le thempheretsha ya mmele ge babereki ba maene ba bereka. Go kiba ga pelo le thempheretsha ya mmele di tla kgona go re bontsha gore ngangego ya popommele ke ye ka kang ge go berekiwa. Sedi ye re e hwetsago e tla kgona go re thusa gore re lebelele mokgwa wo mobebe wo babereki ba ka berekago ka gona mo go nago le ngangego ya popommele ye ntsi.
Taletso ya go tsea karolo: Re go laletsa go tsea karolo resetsheng ya rona ka ge re ka se kgone go tswela pele ntle le thuso ya boithaopi bja gago. Ge o i thaopile go tsea karolo, o tlo kgopelwa go tsea diteko tsa boiketanelo tsa mmele, ke ngaka ye e kgethilwego, ntle le tefelo, go lebelela gore o fihlelela dinyakwa tsa boitekanelo gore o be motsea karolo. Ge o sa di fihlelele, o tla eletswa ka mabaka go reng o sa kgone go ba motseakarolo .
Resetshe ye e amana le eng? Lebaka la resetshe ye, ke go kgona go bona ngangego ya popommele ya bontate le bomme ba berekago maeneng ka nako ye e beilwego. Gore re kgone go dira se, re ka rata ge o ka re dumelela go mesara go betha betha ga pelo ya gago le thempheretsha ya mmele wag ago ge o le mokoting ka nako ya mmereko wagago ge o le gare o bereka. Go betha betha ga pelo le thempheretsha ya gago di tla tsewa fela ka tshifi e tee fela.
Sediriswa seo se tla berekisiwago go mesara go betha betha ga pelo ya gago le thempheretsha ya mmele se bitswa *CorTemp™ Physiological Monitoring System.* Mohola wa sona o ka tsela ye:

1.) Go betha betha ga pelo go tla mesariwa ka di sensara tse di lego ka gare ga raba e sesane ya lepanta leo o tlo leaparago mo kgareng. O mongwe wa di resetshas o tlo go thusa go raretsa lepanta leo le gore le dule gabotse. Ge o feditse ka tshifi o tlo tla gape a rarolla lepanta leo mo go wena.

2.) Thempheretsha ya gago e tla tsewa ka go somisa pilisi yeo o tla go e metsa. Ge e le ka gare ga mmele wa gago go tla berekisiwa data recorder e nnyane ye e tlabego o epare mo dinokeng.

Pilisi ye o tlabego o filwe yona e metsega gabonolo go tshwana le pilisi e nngwe le e nngwe. E ka se tologe ka mo mmeleng go fihla di iri the 18 go ya go tse 30 pele ga ge e tla tswa mo mmeleng ga bonolo.

Ge o dumela go tsea karolo, ngaka warena o tlo go botsisa dipotsiso go netefatsa gore ga o na maemo a maphelo a a ka dirago gore o se kgone go metsa pilisi. Ge a ka hwetsa go na le bothata, o ka se dumelelwe go tsea karolo.

Mabaka ao a ka dirago gore o se dumelelwe go metsa pilisi ke a a latelago:

- Ge mmele wa gago o le boima bja ka tlase ga 40 kg;
- Ge o na le bothata bja go metsa;
- Ge kgokgokgo ya gago e na le bothata;
- Ge o na le bothata bja go hlatsa le go kgamega;
- Ge o na le bothata bja go lomega ka maleng;
- Ge o kile wa dirwa opareisene mo mmepeng;
- Ge o kile wa ba le bothata bja go bofega mala;
- Ge o na le seo ba se loketsego ka mo pelong go thusa go pompa ga pelo;
- Ge e le gore o tlo ya x-rays tse bohlokwa (NMR/MRI Scanning) ka morago ga beke tse pedi.

Babereki ba 80 go tswa maeneneng wa gago ba tlile go laletsiwa go tsea karolo.

Dikotsi: Maemo a tshepidiso ya resetshe ye, a netefaditswe gore o se be ka tlase ga kgatelelo ya stress. Hlahlobo ya mmele le yona e tla netefatsa gore mmele wag ago o se ke wa bakotsing. Ngaka e tla dula e le gona go netefatsa seo. O kgopelwa go botsa o mongwe wa leloko la resetshe goba ngaka ge o ka kwa o sa ikwe gabotse ge go diriwa goba morago ga resetshe. Bona batla netefatsa gore o a lekolwa, tefelo e tla ba go tswa go balaodi ba resetshe.

Ditefelo: A go na ditefelo tse di tla fiwago batseakarolo. Eupsa ge ngagego ya popommele e ka hwetswa e le ye e fetago tekano, pebofatso ya mesomo e boima e tla hlohleletswa.

Go fana ka hlaloso: O na le tokelo ya go botsisa maloko a resetshe mo o sa kwisisego nako e ngwe le e ngwe. Dipoelo tsa popommele di tla ba gona letsatsi morago ga go lekolwa.

Boithaoipi bja go tsea karolo: Go tsea karolo ke boithaopi go tswa go wena. O dumeletswe go gana go ba mo tsea karolo goba go gogela morago nako engwe le engwe ntle le go lefiswa.

Kokeletso ya tefelo: A go na kokeletso ya tefelo ka ge resetshe ye, e tla be e diriwa ka nako ye e beilwego ya tshifi.

Hlaloso ka ga wena: Hlaloso ka ga wena e tla ba sephiri. Leina la gago le nomoro ya pasa di ka se ngwadiwe. Hlaloso e ngwe le engwe ka ga wena e tla notlelelwa ka khabineteng goba ya tshireletswa ka password khomphuteng.

Hlaloso ka ga wena e ka ntshiwa ge fela molao o re bjalo. Mekgahlo ye e ka nyakago go kgonthisisa ka wena go ba motseakarolo mo resetsheng ye, ke mekgahlo ye e tshwanago le Research Ethics Commitee.

Dinomoro tsa mogala tsa di resetshas:

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Dinomoro tsa mogala tsa mongwaledi wa ethics committee

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Maikano a motsakarolo: ke a e kana gore ke badile pampiri ena en eke tlaloganya diteng tsa yona. Ke e kana gore ke boleletswe ka botlalo ebele ke dumetse go ithaopa go tsaya karolo mo projekeng, ebele ke a tlalohanya gore ke ka tlogela nako ngwe le ngwe kwa ntle gago pateletswa ke ope. Ebele ke filwe monyetla wa go botsa dipotso tse diamang tsamaiso ya projeke ena le gore ke dumeletswe go botsa batsamaisi dipotso ka nako ya projeke.

Signature of participant and witness

____________________________ ____________________________

Signature of participant Date

____________________________ ____________________________

Signature of witness Date