Safety in Mines Research Advisory Committee

Final Report

Investigation into slipping and falling accidents and materials handling in the South African mining industry

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Executive summary

The objective of the present study was to analyse information on slipping and falling accidents and materials handling activities in the South African mining industry. Accident data pertaining to slipping, falling and materials handling accidents for the past five years were obtained from the South African Mines Reportable Accident Statistical System (SAMRASS). The information obtained was analysed to identify the causal factors and circumstances under which these accidents occurred.

A limited survey was conducted at a gold mine, a colliery and a quarry to establish current manual materials handling practices. This included walk-through observational surveys of the work facilities to observe obvious ergonomics-related risk factors.

Over the period 1999 to 2002, a total of 2 027 accidents involving slipping and falling were reported. A total of 442 accidents were associated with individuals falling in shafts or excavations, or from structures, and 1585 accidents were the result of people slipping, tripping over objects, stumbling or overbalancing. Inadequacies relating to standards and procedures were stated to be the major probable cause in 37,8% of the fatalities and 33,1% of the accidents associated with injuries. Under the category 'training or placement factors', 'mental or physical limitations' and 'lack of knowledge' were identified as the major causal factors. High-risk occupations in all the categories of falling and slipping accidents are: general miners, rock drill operators, stope team workers, locomotive drivers, winch operators and plant workers.

Despite the complexity of the problems in slipping and falling accidents, some quite simple interventions could be made, such as proper housekeeping, sufficient lighting, and promotion of awareness of the problems. Standards and procedures should be implemented and adhered to, and they should be reviewed on an ongoing basis to ensure that they also take cognisance of safety risks.

More elaborate interventions could include a proper selection of footwear to meet the requirements of the environment where it will be used. In this regard, safety standards for footwear, such as task-related standards, should be developed and adequate selection guidelines for the users should be established. This issue is being addresses as part of SIMRAC Project SIM 03 09 04.

Research is also needed to develop appropriate and functional safety devices for individuals working at box holes, ore passes and in shafts to prevent them from accidentally falling into these excavations.

During 2001 and 2002, a total of 977 accidents involving material handling were reported. Most of these accidents could be related to probable causes falling into five main categories: ‘mental or physical limitations’, ‘standards and procedures’, ‘equipment, tools and materials’, ‘lack of knowledge’ and ‘inadequate leadership and supervision’. Manual material handling activities were associated with a number of workplace factors that could lead to the development of musculoskeletal disorders.

In order to improve material handling on mines, it is recommended that research be focused on the development of a material handling system to be used in stopes, and suitable physical capacity tests to match the special capabilities of individuals with specific manual material handling (MMH) job requirements. The compilation of guidelines on MMH to assist mines with the design of MMH tasks is also recommended.

Table of Contents

Page

List of Tables

Page

1. Introduction

A significant number of injuries in the workplace are attributed to slips and falls. Slipping, tripping or falling accidents can happen on the level, on ramps, on steps and stairs, or from a height, and have differing causes and consequences. In normal walking (locomotion), there is a cycle of the supporting leg pushing off from the toe, the other leg swinging forward to heel strike, body weight transferring forwards onto the heel and then to the toe, the supporting leg pushing off from the toe, and so forth. Slipping occurs when the friction between the foot and the floor is insufficient to prevent movement between the two surfaces. Leamon (1992) described the three categories of slip: a *microslip* of < 20 mm, a *slip* of between 80 and 100 mm, and a *slide* of > 100 mm. Microslips and slips are less of a problem, as even when they are detected by an individual, the individual is likely to be able to maintain his or her balance. Slides, however, may become unrecoverable, leading to body impact and the possibility of injury.

Slipping can occur during either the *toe off* or *heel strike* phases of walking, although a slip during the latter is usually more hazardous. This is because during heel strike, the forward momentum of the body is in the same direction as the slip. Most slips occur where the properties of a walking surface change suddenly. Several sensorimotor systems are used by humans to maintain upright static posture and dynamic balance during locomotion. The central nervous system rapidly and accurately processes the sensory inputs from vestibular organs and vision and, when posture or balance are challenged during a sudden slip or trip, a co-ordinated neuromuscular motor response is needed to re-establish the balance to avoid a fall.

Certain protective gait adaptations are aimed at regulating gait in hazardous situations, for instance in slippery conditions. A reduced stride length decreases the horizontal (shear) force component during both the toe off and heel strike phases of walking, leading to increased stability and making it possible to maintain balance on slippery surfaces. However, this requires both detection of and adjustment to the walking conditions (Haslam, 2001).

Tripping is less common than slipping and occurs when the foot catches on an obstacle or object, with continuing motion of the body, resulting in a stumble or fall. Tripping hazards may be fixed features in an environment, such as a raised step, or temporary items, such as loose rocks. Marletta (1991) suggested that irregularities of as little as 7 mm might be sufficient to induce tripping. As with slipping, detecting changes in the walking surface or the presence of an object in the way allows avoidance.

Falls on the level are the most frequent type of fall in industrial settings, with slips occurring more frequently than trips. Injuries from falls on the level are commonly sprains and strains, followed by contusions, with the wrist, arm, ankle and back being the body areas most affected. On ramps, the shear forces between footwear and the floor at toe off and heel strike increase with gradient. The risk of heel slip and falling backwards when descending a ramp is greater than the risk of slipping during toe off and falling forwards when ascending.

Certain manual handling tasks seem likely to increase the risk of fall accidents. Carrying a load affects a person's centre of gravity, potentially making it more difficult to recover from imbalance. During pushing and pulling, shear forces between the feet and the floor can be very high, increasing the chances of slipping. Personal characteristics involved in slipping, tripping and falling accidents are gait, balance, stature, strength, vision and behaviour. These in turn may be influenced by health, age, fatigue, environment (e.g. lighting and restricted spaces) and activity.

In general, materials handling is the movement and handling of goods from the point of supply to the point of use. The movement of materials can be completed as a single operation or can be part of a complex system in which the material is subjected to a number of operations during its journey. The latter is the case in a typical South African mine.

The manual handling of materials and tools is an essential aspect of the work to be carried out in a workstation in almost any workplace. The term *manual handling* includes lifting, pulling, putting down, pushing, carrying, moving, holding and restraining. Every time that heavy loads are moved by people or machines, there is a risk of an accident due to the characteristics of the load or unfavourable ergonomics conditions. Manual materials handling (MMH) has been identified as a potentially harmful physical work factor (Bernard, 1997; Kuiper et al., 1999).

While most countries acknowledge the problem that MMH creates for workers, accurate statistics of injuries attributable to MMH are still hard to find. According to Sweden's National Board of Safety and Health (1983), the most common types of injury to workers in that country are strains and sprains due to overexertion of body parts. When injuries are classified by occupation, the category 'materials and goods packaging' accounts for more than 23% of injuries, by far the largest proportion of any one segment of their labour force. Mechanisation and automation have eliminated MMH to a large extent in some industries. However, there are still workplaces where people are physically overloaded by lifting and carrying heavy loads. This is particularly evident in industries where many workplaces are still labour-intensive, despite a high degree of mechanisation.

There is close interaction between the body's physiological characteristics, its capacity and work requirements. The characteristics of the workplace determine the postures and workload for both static and dynamic tasks such as in MMH. The loads to be handled, the weight and type of tool used, as well as the dimensional characteristics of the workplace (e.g. confined spaces), force the body into a certain posture or a combination of postures.

Musculoskeletal disorders associated with MMH can be determined by organisational, environmental, postural and psychosocial factors. Work organisation, both physical and temporal (duration of tasks, distance, frequency of loads and adequacy of recovery time), would also have an impact on the workload. Lifting tasks are also influenced by the load itself, depending on its shape, stability, size, weight, location and slipperiness. Environmental factors, such as poor lighting, a cluttered or uneven floor and poor housekeeping, may all be the cause of accidents (Forastieri, 2001). A significant number of MMH accidents have a lasting effect and sometimes lead to permanent disability of the victim. The most frequent accidents due to MMH are: physical strain, loads falling on people, people trapped between objects, people falling, hits, blows and cuts from loads, and injuries caused by sharp edges on equipment or loads (Hakkinen, 1998).

2. Objective of study

The objective of the present study was to analyse information on slipping and falling accidents and materials handling activities in the South African mining industry. The primary outputs of the study are:

- an analysis of slipping and falling accidents and identification of the workplace factors influencing slipping and falling
- an analysis of the ergonomics factors associated with materials handling

- the identification of interventions to reduce these hazards
- the identification of research needs, outlining the necessary investigations.

3. Methods

Accident data pertaining to slipping, falling and materials handling accidents for the past five years were obtained from the South African Mines Reportable Accident Statistical System (SAMRASS), managed by the Department of Minerals and Energy. The information obtained was analysed to identify the causal factors and circumstances under which these accidents occurred.

A limited survey was conducted at a gold mine, a colliery and a quarry to establish current manual materials handling practices, with specific reference to load (mass) limits, mechanical aids and educational aspects. This included walk-through observational surveys of the work facilities to observe obvious ergonomics-related risk factors and informal discussions with health and safety representatives and workers.

On completion of the above phases, meetings were held with mining personnel to discuss the findings and also to identify potential strategies for preventing accidents related to slipping, falling and materials handling. Possible aspects for future further research and investigations were also identified.

4. Results and discussion

4.1 Falling and slipping accidents

4.1.1 SAMRASS system

Over the period 1999 to 2002, a total of 2 027 accidents involving slipping and falling were reported. During the review period, 69,6 % of these accidents occurred at gold mines, 13,0% at platinum mines and 5,8 % at collieries. A total of 442 (21,8%) accidents were associated with individuals falling in shafts or excavations, or from structures, and 1 585 (78,2%) accidents were the result of people slipping, tripping over objects, stumbling or overbalancing (Table 4.1). Sixteen per cent of the 'falling in' and 'falling from' accidents were fatal, with the highest fatality rate associated with falling in shafts (68% of the accidents in this category) and falling in excavations (35% of the accidents in this category). Fatality rate from slipping, tripping, stumbling or overbalancing accidents was 0,7%.

Table 4.1: Accidents resulting from falling, slipping and tripping: all mines (1999 – 2002)

Accident classification	Code	Fatalities	Injuries	Accidents
Falling in shafts	04C001	17	8	25
Falling in excavations	04C002	31	58	89
Falling from structures	04C003	22	246	268
Falling from machines	04C004	1	59	60
Total		**71**	**371**	**442**
Slipping	04D001	7	1 050	1 057
Tripping over	04D002	2	179	181
Stumbling	04D003	1	157	158
Overbalancing	04D004	1	188	189
Total		**11**	**1 574**	**1 585**

The major probable causes of the above accidents are summarised in Table 4.2.

Table 4.2: Summary of major probable causes of accidents resulting from falling, slipping and tripping: all mines (1999 – 2002)

Probable cause of accident	Code	Fatalities n = 82	Injuries n = 1 945
		(%)	**(%)**
Training or placement factors			
Mental or physical limitations	01	17,1	22,6
Lack of knowledge	02	14,6	24,9
Personal factors		1	
Inadequate leadership and supervision	07	3,7	2,6
Job factors			
Equipment, tools and materials	11	13,4	10,0
Standards and procedures	12	37,8	33,1
Other factors		13,4	6,8

From Table 4.2 it is evident that inadequacies relating to standards and procedures were the major probable cause in 37,8% of the fatalities and 33,1% of the accidents associated with injuries. In this category, the inadequate maintenance of standards, the lack of specific rules to control the actions that lead to incidents and inadequate methods for the identification of hazardous tasks were identified as the major probable causes. Under training or placement factors, 'mental or physical limitations' and 'lack of knowledge' were identified as the major causal factors. In the 'mental or physical limitations' category, poor judgement was identified as the major causal factor in all the accidents under review. 'Inadequate leadership and supervision' were identified as probable causal factors in 3,7% of the accidents resulting in a fatality, and in 2,6% of the accidents resulting in injuries.

A summary of the major probable causes leading to 'falling in' and 'falling from' accidents is given in Table 4.3.

Table 4.3: Major probable causes of 'falling in' and 'falling from' accidents: all mines

Probable cause of accident	**Code**	**Fatalities**	**Injuries**
		(%)	**(%)**
Training or placement factors			
Mental or physical limitations	01	33,3	44,3
Lack of knowledge	02	14,8	
Personal factors		1	
Abuse or misuse of tools/equipment, etc.	06	3,7	4,3
Inadequate leadership and supervision	07	7,4	5,7
Engineering	08		5,7
Job factors			
Maintenance	10	11,1	4,3
Equipment, tools and materials	11	7,4	10,0
Standards and procedures	12	18,5	20,0

From Table 4.3 it is evident that approximately 33% of the fatal accidents and 44% of the non-fatal accidents were associated with 'mental or physical limitations', with 'poor judgement' by the accident victim being given as the major underlying cause. Lack of knowledge, inadequate standards, the lack of Codes of Practice, inadequate task analysis and procedures systems, and inadequate communication of standards were also identified as major causal factors.

Accidents in which people fell down shafts were generally associated with slipping from the examination conveyance in the shaft and with the loading of equipment and materials into skips and cages. Ore passes, box holes and tips were also identified as dangerous areas in terms of 'falling in' accidents. In many of the accidents in these areas, people slipped and fell into the excavations, or they were standing on top of broken ore "when the stope box was pulled", for example. Scaffolds, temporary platforms, drill carriages, travelling ways and ladders (wooden and chain) were also identified as potentially dangerous work areas.

The major probable causes of accidents resulting from slipping, tripping over objects, stumbling or overbalancing is given in Table 4.4.

Table 4.4: Major probable causes of accidents in the 'slipping', 'tripping over', 'stumbling' and 'overbalance' categories: all mines

Probable cause of accident	Code	Injuries
		(%)
Training or placement factors		
Mental or physical limitations	01	57,4
Lack of knowledge	02	9,0
Job factors		
Standards and procedures	12	13,0
Other factors (various)		20,6

Training or placement factors and job factors were the major probable causal factors here (Table 4.4). 'Poor judgement' (which forms part of the training and placement factors) was adjudged to have played a major role in approximately 37% of the accidents. Other training and placement factors included poor co-ordination, man-job specifications not being made available to medical officers, and workers working without having undergone a pre-placement medical examination. The probable causal factors in the 'lack of knowledge' category were inadequate training material and a lack of knowledge regarding the safety aspects of the job. Job factors identified as probable causes related to standards and procedures, with specific reference to the absence of specific procedures for controlling the actions that led to the accidents, and inadequate methods for identifying hazardous tasks.

The majority of slipping and falling accidents occurred in stopes, gullies, walkways and haulages. The activities associated with these accidents include drilling, sweeping, barring, using ladders, pulling cables or ropes, pushing material cars, manual materials handling (MMH), and climbing onto and down from mining machinery.

High-risk occupations in all the categories of falling and slipping accidents are: general miners, rock drill operators, stope team workers, locomotive drivers, winch operators and plant workers.

4.1.2 Results from mine interviews

In addition to the causal factors identified in SAMRASS, safety personnel at the project mines mentioned the following as probable workplace-related factors in accidents involving slipping and falling:

? Poor lighting in general and especially in high-risk areas (in many cases the individual's cap lamp is the only light source in underground work areas)
? Poor housekeeping
? Stairways and walkways without proper handrails
? Ladders (often make-shift) not standing on a firm basis and in many cases not extending beyond the landing level
? Ladder rungs not properly secured to the stile
? Incorrect use of chain ladders
? Working platforms without guardrails
? Unstable scaffolds
? Non-adherence to mine standards and safety precautions
? Inadequate supervision
? Incorrect use of personal protective equipment and safety devices
? Safety footwear not providing enough support around the ankle and heel regions
? Safety footwear not providing proper coupling between the wearer and the floor
? Unsafe work practices
? Unsure footing when walking/working on uneven or unstable surfaces, especially when carrying loads
? Wet, muddy and slippery conditions

- Locomotion in an unnatural body posture as a result of restricted ceiling heights and gradients
- Worker fatigue, especially in hot environments
- Ineffectiveness of safety devices
- Potentially risky situations not assessed on an on-going basis
- Inadequate or irregular workplace inspections
- Delayed institution of remedial actions in high-risk situations.

4.2 Falling and slipping: Conclusions and recommendations

The causes of slipping and falling accidents are multifactorial and a complex interaction between workplace factors, work organisational factors, and personal factors related to the individual involved in the accident.

Despite the complexity of the problems in slipping and falling accidents, some quite simple interventions could be made, such as proper housekeeping, sufficient lighting, and promotion of awareness of the problems. Standards and procedures should be implemented and adhered to, and they should be reviewed on an ongoing basis to ensure that they also take cognisance of safety risks (as is required in Section 11.2 of the Mine Health and Safety Act (Act No.29 of 1996).

More elaborate interventions could include a proper selection of footwear to meet the requirements of the environment where it will be used. In this regard, safety standards for footwear, such as task-related standards, should be developed and adequate selection guidelines for the users should be established. This will be pursued in SIMRAC Project SIM 03 09 04.

Research is also needed to develop appropriate and functional safety devices (restraint belts and fall arrestors, for example) for individuals working at box holes, ore passes and in shafts to prevent them from accidentally falling into these excavations.

4.3 Manual materials handling (MMH) accidents

Accidents involving the manual handling of materials over the period 2001 to 2002 are given in Table 4.5.

Table 4.5: Accidents involving the manual handling of materials over the period 2001 to 2002

Accident classification	Code	Fatalities	Injuries	Accidents
Loading	04B101	0	106	106
Offloading	04B102	0	103	103
Carrying	04B103	0	121	121
Rolling	04B104	0	30	30
Pushing	04B105	0	135	135
Pulling	04B106	0	137	137
Lifting	04B107	2	248	250
Lowering	04B108	0	95	95
Total		**2**	**975**	**977**

The major probable causes of the above accidents are summarised in Table 4.6.

Table 4.6: Major probable causal factors of manual materials handling accidents

Accident category	SAMRASS Code	Major probable causal factors
Loading	04B101	Mental or physical limitations (44%) Standards and procedures (15%) Equipment, tools and materials (5%)
Off-loading	04B102	Mental or physical limitations (50%) Abuse or misuse of tools and equipment (23%) Standards and procedures (23%)
Carrying	04B103	Mental or physical limitations (40%) Standards and procedures (16%) Lack of knowledge (7%)
Rolling	04B104	Standards and procedures (23%) Mental or physical limitations (20%) Lack of knowledge (10%) Equipment, tools and materials (10%)
Pushing	04B105	Mental or physical limitations (43%)

		Standards and procedures (21%) Equipment, tools and materials (8%)
Pulling	04B106	Mental or physical limitations (46%) Standards and procedures (19%) Lack of knowledge (10%) Equipment, tools and materials (8%)
Lifting	04B107	Mental or physical limitations (37%) Standards and procedures (19%) Lack of knowledge (14%)
Lowering	04B108	Mental or physical limitations (44%) Inadequate leadership and supervision (13%) Equipment, tools and materials (9%) Standards and procedures (9%)

From Table 4.6 it is evident that most of the accidents involving the manual handling of materials could be related to probable causes falling into five main categories: ‘mental or physical limitations’, ‘standards and procedures’, ‘equipment, tools and materials’, ‘lack of knowledge’ and ‘inadequate leadership and supervision’. ‘Poor judgement’ (which forms part of training and placement factors) was adjudged to have played a major role in these accidents. In the ‘standards and procedures’ category, inadequate maintenance of standards, inadequate task analysis systems and inadequate methods for identifying hazardous tasks were the major causal factors. As far as the ‘equipment, tools and materials’ category is concerned, failing to use available equipment and tools, and the use of incorrect equipment were the prominent causal factors. A lack of knowledge of regarding the safety aspects of the job also played a major role in a number of the accidents.

Since 2001, ‘poor judgement’ has been identified as the major probable cause of accidents. Although the reason for the classification is not apparent from SAMRASS, it may, at least in part, be linked to the lack of knowledge and the identified shortcomings in the maintenance of standards.

4.4 SAMRASS system

In its current format, SAMRASS is an excellent system for collecting general statistics on accidents in the South African mining industry. However, if more detailed information on the probable causes of accidents and more detailed accident descriptions are required, as was the case in this project, the current information in the system does meet all the requirements. This could, at least in part, be ascribed to the absence of relevant and important information that may have played a role in the accident and were confirmed by on-site observations. For example, a number of environmental factors, such as the thermal environment, poor illumination and noise, are known to play an important role in accident causation. A more detailed reference to these factors in SAMRASS would without doubt add value and assist in the closer scrutiny of the circumstances associated with accidents in the mining environment.

More detailed information would also assist accident investigators to determine more accurately the factors contributing to accidents which would, in turn, be useful in deciding on which interventions and countermeasures should be instituted to prevent the recurrence of such accidents.

In the current system, a number of the accident descriptions seem to contradict the causal factor. For example, the probable causal factor for a manual materials handling accident in which the worker was “struck by pipe while installing it” was given as “pre-placement medical examination not done”. With the limited information available in SAMRASS, it is difficult to establish the link between these two factors or if the correct data were supplied.

4.5 Material handling practices

Generally speaking, material handling is the movement and handling of goods from the point of supply to the point of use. The movement of material can be completed as a single operation or can be part of a complex system in which the material is subjected to a number of operations during its journey. The latter was the case for the three sites visited.

The handling of materials on surface was very similar at all the sites visited. Most of the materials are delivered to the mine store or an acceptance depot, off-loaded (in most cases manually), stored, and then loaded onto material cars or other designated vehicles for transfer to the destination underground via the shaft system.

In the case of the deep level mine, trucks delivering timber and other support elements are off-loaded by overhead cranes or forklifts. Thereafter, they are loaded (in many cases manually) onto material cars (trackbound) and transported to the shaft head by either a locomotive or a puller (normally an adapted tractor) for transfer underground.

At the quarry, trucks were used for the transport of materials and very little manual material handling takes place.

The horizontal underground transport system begins at the shaft and ends at the working faces. The material transport systems used underground includes trackbound transport, trackless equipment, and monowinch and monorope systems.

In the trackless system (colliery), tractor-trailers, trucks and specialised transport vehicles are used to move materials to the final destination and the system is less complex than that of a gold mine. In most cases, the handling of materials (loading/off-loading) takes place without the assistance of handling equipment.

In the case of the gold mine, material is brought into the mine on trackbound systems and transferred from the crosscut to the reef horizon by using monowinch systems. The bulk of the material is transported in open flattop cars, V-sided cars, and cars specially designed to suit the payload. Examples of the latter are explosives cars, drill steel cars, side tippers and long material cars. As is the case in the colliery, the handling of materials (loading/off-loading) takes place without the assistance of handling equipment, almost without exception.

Most of the material transported in cars was timber, mechanical steel props, and elongates. The handling and transportation of multiple timber units are difficult and time-consuming tasks, with numerous rehandling points along the supply route. In addition, heavier material is required to be transported by chain blocks or other methods, which causes severe delays in the delivery system.

The in-stope handling system begins at the crosscut storage area and ends at the working face. In the gold mine, the crosscuts are important conduits for all incoming and outgoing materials and people to the production horizon. At this point, material is manually unloaded from the cars to a storage position, and then rehandled to the position of the monorope installation. Judging from the congestion of materials observed at this point, there appears to be insufficient storage space.

The stoping operations in narrow tabular ore bodies are served by monowinch installations. Installed in cross-cuts as close as possible to the timber supply, the steel ropes are reeved through a series of pulley blocks to follow the route chosen for the material to travel, usually to the top of the panel. The material is then transported manually downdip along with the length of the face. In other cases, the material is manhandled by human 'chains' to the face, whereby individual units are 'thrown' or 'dragged' forward until the units reach the face. Material is also transported by means of a gully scraper to the panel face.

Two methods are used for loading materials when a monowinch system is used to transport materials to the stoping areas. The one method uses a loading magazine onto which the item is tied using twine. The twine is then slid off the pipe and over the rope. When this method is used, the monowinch motor is not stopped for loading. The other method involves starting and stopping the motor at intervals to allow the worker to fasten the items directly onto the monorope.

The MMH activities in the stope vary. The drilling machine operator was involved in manually carrying the drilling equipment when the rockdrill was transported from the storage area to the drilling site and back. The average mass of pneumatic rock drills is approximately 25 kg, depending on the type and model of the rockdrill. Moving the rockdrill and associated drilling equipment in the stope and positioning it to commence drilling were impeded by the need to adopt a variety of awkward postures as result of the restricted workspace.

General team workers are responsible for keeping the stope panel up to date by installing supports and assisting with general construction work in this area. Their tasks include the barring down of dangerous hanging walls by means of a pinch bar, clearing loose rock away from the stope face, transporting and installing props and packs, and transporting and erecting blast barricades. General construction tasks include installation of grizzles, box fronts and chutes, building of walls, and assisting with pipe and rail extensions.

The installation of support involves lifting and carrying. The sticks are lifted from the floor with both hands directly in front of or sideways to the body. The stick is held by one of the workers while another worker places the hydraulic pot in position. The sticks are lifted at an asymmetrical angle with a twisted trunk. The horizontal location of the hands and the vertical lifting distance varied from one lifting activity to the next.

During observations of the tasks, 500 mm and 750 mm long timber blocks were used to construct the timber packs. The timber blocks are tied in flat bundles of three and four blocks with a mass of 13,5 and 16,4 kg.

Pack builders lift the timber from the floor with both hands directly in front of or sideways to the body. Lifting heights ranged from ankle height (usually in a stooped posture) to above sitting shoulder height whilst adopting twisted and bent postures.

4.6 MMH: Ergonomics-related risk factors

Any manual handling basically constitutes a risk for injury. Factors that contribute to the risk include the task, the load, the work environment, work organisation and individual capability. During the observation of MMH activities, the following ergonomics-related risk related factors (Mital *et al*., 1997) were observed:

4.6.1 Static work

Almost all the MMH activities observed in the mining environment have both static and a dynamic component. In some tasks, the dynamic component is the major one (e.g. in repetitive lifting tasks), while in other tasks, the static component is the dominating component (e.g. in holding and carrying tasks). Static work or effort is characterised by the contraction of muscles over extended periods, such as when a postural stance is adapted for a prolonged period. The physiological effects of static work include the compression of blood vessels, lack of oxygen supply to cells in the muscle, an increasing loss of strength, and eventually pain.

Static endurance (the time that a load can be held without significant movement) is an important predictor of maximum acceptable weights of lift (Mital and Ayoub, 1980; Mital and Manivasagan, 1984), and holding time decreases significantly as the load being held becomes heavier (Ayoub *et al*., 1987). This finding is of significance considering that in many cases, workers involved in the manual handling of materials in mines are required to hold an object in place while loading it onto a vehicle or fastening it to another surface.

4.6.2 Restricted workspaces

Having to perform MMH activities in restricted spaces is a common occurrence in the mining industry and many MMH tasks are performed in unusual postures. Posture greatly affects the ability of the muscles to generate power. When muscles generate forces in a deviated position, they have to generate higher internal forces to accomplish the same task.

In spite of awareness of the spatial restraints in the workplace, limited attention has been directed at quantifying the effects of spatial restraints on MMH task performance. It is known, however, that limited headroom has a negative effect on lifting capacity (Ridd, 1985) and that when loads are carried through confined passages, the load-carrying capacity declines substantially (Mital, 1986). If the workplace does not allow erect posture, the carrying load should be reduced by 1% for each degree of trunk flexion from the erect posture (Ridd, 1981). The lifting capacity of loads is also drastically reduced when unusual body postures are adopted (Mital *et al.*, 1997). Inadequate workspace also leads to a constant reorientation of load, postural instability, and slower and more cautious movements.

4.6.3 Unusual body postures/poor handling techniques

Unusual body postures not only change the force requirements, but also cause the work to become very strenuous, particularly when the work is predominantly static in nature (Burdorf *et al.,* 1993). For MMH activities that have a dominating dynamic component, the body may assume different postures. Turning and twisting while handling materials (postures that were frequently observed) lead to an increase in spinal stresses and intra-abdominal pressures and are also associated with an increased incidence of lower back disorders (Christensen *et al.,* 1995). The task is also perceived to be more difficult. From an ergonomics viewpoint, the poor design of material cars was an important cause of both stooped body postures and overreaching when loading or off-loading materials.

4.6.4 Repetitive handling

Frequency of handling is one of the most critical task characteristics that influence an individual's capacity to perform MMH activities. In general, the MMH capacity increases as the frequency of handling decreases. A reduction in the frequency of handling is also associated with an increase in the endurance time (Jomoah *et al.,* 1991).

4.6.5 Asymmetrical lifting and carrying

Asymmetrical lifting and carrying (which is the rule rather than the exception with MMH in mining) lead to reduced lifting and carrying capabilities and reduced isometric strength. They also result in increased intra-abdominal and intra-disc (spinal) pressures. According to Garg and Badger (1986) the decline in manual lifting capacity caused by asymmetrical lifting and carrying could range from 8.5% to 22%, subject to the movement of the feet.

In a realistic situation, such as unloading material from a vehicle, the starting and end locations of the load change continuously. The feet, therefore, move constantly. In the unlikely event that the feet remain in a fixed position, the spinal column twists and this will lead to a reduction in MMH capability. If the feet move, the reduction in MMH capability is smaller and the task is less stressful. Sideways movement also subjects the spine to a lateral bending moment that could reduce the MMH capability by up to 16% (Ayoub and Mital, 1989).

4.6.6 Heat stress

High environmental temperatures were observed in the gold mine. Heat stress influences an individual's physiological and psychological behaviour and is associated with discomfort, all of which lead to a reduced work rate, a feeling of fatigue and increased accident rates. According to Snook and Ciriello (1974) MMH capacity also declines: lifting capacity may decline by 20%, pushing capability by 16%, and carrying capability by 11% when the ambient temperature increases from 17 °C to 27 °C. Hafez (1984) observed a 12% reduction in the manual lifting capabilities of heat-acclimatised subjects when the heat stress increased from 32 °C wet-bulb globe temperature (WBGT); no decline in capacity was observed up to 27 °C WBGT.

4.6.7 Heavy equipment

A load is generally characterised by its shape, size and weight. The weight of the load is perhaps the most important load characteristic in situations in which the load will be handled manually. Many of the objects handled by individuals as part of material handling in mining exceed the guidelines of the International Labour Organization (25 kg for males between the ages of 20 and 35 years, and 15 kg for females in the same age category). The recommendation of the National Institute of Occupational Safety and Health (NIOSH) for lifting and lowering tasks is 23 kg, which corresponds closely to that of the International Labour Organization.

Depending on the type, the weight of props used for support in underground workplaces in the gold mine ranged from 14,5 to 52,5 kg and they were carried from the storage area to the actual workplace. In the colliery, for example, the roof bolter operator was lifting bundles of roof bolts ranging between 10 and 15 kg. onto the deck of the machine. The recommended weight limit (RWL) from NIOSH for this particular task is 6,9 kg and the lifting index (LI) is 3.6 (Mital *et al.,* 1997). Tasks with a lifting index greater than 1.0 pose an increased risk of lifting-related lower back pain. The risk is increased due to the operators lifting below the waist and above the shoulders.

4.7 MMH: Possible interventions

In the case of MMH risk control is best accomplished by a combination of efforts to eliminate manual handling, the introduction of mechanical handling equipment, and the provision of suitable training. In practice, the reduction of loads and improved handling training will be the first line of control while more effective long-term solutions are found.

The primary approach to preventing work-related musculoskeletal disorders due to the manual handling of loads is the ergonomics redesign of work in order to optimise the workload. Guidelines for designing safer work practices should consider the following principles:

Engineering controls

? Eliminate manual lifting and carrying of loads by using mechanical and automated handling instead Provide appropriate handling equipment (e.g. hoists, lifting platforms, fork-lifts, etc.).
? Make loads lighter and/or easier to push and pull.
? Package materials in a form suitable for handling.
? Make loads easier to grasp or carry.
? Provide handles or other holding points on the object to be handled to help with gripping.

Administrative measures

? Spread the burden of carrying loads among a group of workers for a limited period of time, instead of having a single worker involved all day in that task.

? Provide enough space for materials handling operations.
? Refrain from materials handling methods that require climbing and working at high levels to avoid risk of falling.
? Provide good visibility by means of appropriate illumination, especially in critical areas.
? Take into account varying physical capabilities.

Personal protective equipment and training

? Supply workers with appropriate personal equipment for handling tasks.
? Provide adequate and appropriate training for workers undertaking the task.

4.8 MMH: Recommendations for further research

There was general agreement amongst mining personnel that the handling of materials must be done as efficiently as possible. Material handling systems should be site-specific and specifically designed to suit the needs of the materials being handled and transported. The requirements for an ideal system vary, depending on the operational requirements. Mining personnel involved in high-speed developing on mines need materials to be available “just in time”. Because of the lack of storage space, tracks, pipes and other materials should preferably be available precisely when they are needed.

There is a need to address the work and individual factors that contribute to the occupational health and safety risks associated with the manual handling of material. The institution of risk control measures such as eliminating or minimising the manual handling component of materials handling and focussing on mechanical handling equipment are attractive options.

From a macro-ergonomics viewpoint problems experienced with material handling scheduling, which results in materials reaching their destination ‘late’, and inadequate storage space need to be addressed. The need for a relatively inexpensive but reliable computer-based real-time system to assist with scheduling is indicated.

Gold mining personnel expressed the view that in-stope material handling should preferably be ‘hands-free’ from the crosscut to the point of use. Ideally, the system should be capable of carrying all material loads in the stopes and delivering materials to all end-points. Such a system will reduce the need for the manual handling of materials, especially in the confined spaces of stopes, thereby reducing the risk of musculoskeletal disorders.

Supplying material on palettes would facilitate material handling and minimise the manual component thereof. Materials should be transported without having to be unloaded and transferred between stockyard and working place. Ideally, material should be packaged in the same state as required in the working place and the introduction of material cars with frictionless beds can assist with this. The feasibility of this option needs further investigation.

Good design of workplaces and tasks is one of the strategies for preventing musculoskeletal injuries. However, in view of the large variation in body dimensions and mechanical work capacity of the mine worker population, as well as technical and physical constraints in the mining environment, it is not always possible to accommodate all individuals, especially when manual material handling is involved. It is therefore recommended that the selection of workers based on their functional biomechanical strength capabilities, as well as appropriate worker training, be considered as components of a comprehensive plan for preventing musculoskeletal injuries.

In view of the above, it is recommended that future research activities should focus on the following areas:

? The development of a material handling system to be used in stopes
? The evaluation of best practice guidelines on manual material handling to assist mines with the design of MMH tasks
? The development of a suitable physical capacity assessment matrix to match the special capabilities of each individual with specific MMH job requirements.

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